Tony Flenmark

POWER PRODUCTION IN FUTURE EUROPEAN NAVY AND COAST/BORDER GUARD VESSELS

Degree Programme in Maritime Management

2019

Satakunnan ammattikorkeakoulu
Satakunta University of Applied Sciences

POWER PRODUCTION IN FUTURE EUROPEAN NAVY AND COAST/BORDER GUARD VESSELS

Flenmark, Tony
Satakunta University of Applied Sciences
Degree Programme in Maritime Management
May 2019
Pages: 73
Appendices: 1

Keywords: naval fleet, machineries, coast guard, technical development

---

Fast combat vessels have been built almost in the same way since the early 1900s. There are several old-established machineries lay-out used in combat vessels, the most common of them being, due to the speed demand, diesel engine – gas turbine combination. Naval administrations are clearly eager to build more energy-efficient and environmentally friendly combatant and non-combatant vessels. In this development, machinery manufacturers want to be involved in earliest possible stage.

The purpose of this thesis was to compare current machineries used in naval combatant and non-combatant vessels and to explore the possibility to use new technologies in future newbuilding vessels. The use of rules and regulations for the construction of warships was also worth exploring, especially since their use was found to be very different in comparison to the construction of merchant ships. The age distribution of the different vessel classes was also studied with a view to perceiving potential future building projects that the subscriber of this thesis would be able to participate in.

Even if the machinery solutions are constantly being developed to more energy efficient and environmentally friendly, only some of these solutions will probably be used in the future. The intention was also to perceive the most likely future machinery solutions to combatant and non-combatant vessels.

Warfare vessels covered in this thesis were divided into two main groups, combatant and non-combatant vessels and into two subdivisions, vessels operating in ice covered areas and open water vessels. Division into main groups was found necessary because machinery, hull and speed requirements differ significantly depending on the purpose of these vessels. Likewise, the possibility of using new technologies on these ships is very dissimilar.

EUROOPAN LAIVASTON JA MERI/RANNIKKOVARTIOSTON ALUSTEN KONEISTOJEN KEHITYS TULEVAISUUSSA

Tony Flenmark
Satakunnan ammattikorkeakoulu
Degree Programme in Maritime Management
Toukokuu 2019
2019
Sivumäärä: 73
Liitteitä: 1

Asiasanat: sotalaivasto, laivakoneistot, vartiolaivat, tekninen kehitys

---

Sota-aluksista nopeat taistelualukset on perinteisesti rakennettu samalla tekniikalla jo 1900 -luvun alkupuolelta. Koneistojärjestelyissä todettiin olevan muutamia vakiintuneita ratkaisuja, joista kaasuturbiini-diesel -yhdistelmän todettiin ollen yleisin nopeusvaatimusten takia. Koneistojen tekniikan kehittyessä ja ympäristöajattelun muuttuessa sotalaivastoissa on selkeästi noussut esille ajatus siitä, että taistelualusten koneistoja haluttaisiin muuttaa energiatehokkaampaan ja ympäristöystävällisempään suuntaan. Tässä kehityksessä koneistojen valmistajilla on ratkaiseva rooli.

Tämän opinnäytetyön tavoitteena oli vertailla niin taistelualuksissa kuin tukialuksissa nykyisin käytettäviä koneistoratkaisuja sekä tutkia koneistoihin suunnitteilla olevia tai mahdollisesti tulossa olevia muutoksia, joihin koneistovalmistajan tulisi kiinnittää huomiota. Työssä selvitettiin myös eri alusluokkien ikäjakauma, jonka avulla työn tilaajan olisi mahdollista ennakoida minkä tyypin aluksia tullaan rakentamaan ja millaisilla koneistoilla. Sota-alusten rakentamiseen sovellettavien sääntöjen ja määräysten tutkiminen todettiin myöskin tarpeelliseksi koska niiden käyttö erosi huomattavasti kauppa-aluksien rakentamisessa normaalisti käytetyistä säännöistä ja määräyksistä.

Vaikka koneistoratkaisuja kehitetään jatkuvasti energiatehokkaampaan ja ympäristöystävällisempään suuntaan, luultavasti vain joitain näistä ratkaisuista tullaan laajemmin käyttämään tulevaisuudessa. Yhtenä tarkoituksena olikin yrittää kokonaiskuvan avulla hahmottaa mikä olisi se luultavin tulevaisuuden koneistoratkaisu niin taistelualuksissa kuin tukialuksissa.

Tässä päättötyössä käsiteltävät alukset jaettiin kahteen pääryhmään, taistelualukset ja tukialukset, sekä näiden kahteen alaryhmään, jäissä käytettävät alukset ja avovesiolosuhteiden alukset. Pääryhmiin jakaminen todettiin tarpeelliseksi koska aluksien koneistot, rungot ja nopeusvaatimukset poikkeavat huomattavasti toisistaan käyttötarkoituksen takia. Myös mahdollisuuksissa uuden teknologian käyttämiseen on eroa näiden alusryhmien välillä.

CONTENTS

ABBREVIATIONS

1/ ρ	Fuel density
ABS	American Bureau of Shipping
AC	Alternating Current
ANEP77	Allied Naval Engineering Publication
ANSI	American National Standards Institute
AOPV	Arctic Offshore Patrol Vessel
ASTM	American Society for Testing and Materials
BESS	Battery Energy Storage System
BV	Bureau Veritas
CEO	Chief Executive Officer
Cl	Consumption in litres
CO_2	Carbon Dioxide
CODAD	Combined Diesel and Diesel
CODAG	Combined Diesel and Gas
CODAG-WARP	Combined Diesel and Gas – Water jet and Refined Propeller
CODAGE	Combined Diesel and Gas Electric
CODLAG	Combined Diesel-electric and Gas
CODLOG	Combined Diesel-electric or Gas
CODOG	Combined Diesel or Gas
COGAS	Combined Gas and Steam Turbines
COGOG	Combined Gas or Gas
CONAS	Combined Nuclear and Steam
ConOpS	Concept of Operations Statement
COSAG	Combined Steam and Gas
CPF	Canadian Patrol Frigate
CPP	Controllable Pitch Propeller
CSC	Canadian Surface Combatant
DC	Direct Current
DF	Dual Fuel
DNV-GL	Det Norske Veritas – Germanischer Lloyd

EHM	Engine Health Monitoring system
FBG	Finnish Border Guard
FS	Fighting Ship
FT-SPD	Fischer-Tropsch Hydro Processed Synthetic Paraffin Diesel
g/kWh	Grams per Kilo Watt hour
GE	General Electric
GT	Gas Turbine
HDMS	His/Her Danish Majesty's Ship
HEFA	Hydro Processed Esters and Fatty Acids
HMS	His/Her Majesty's Ship
HRS	Hellenic Register of Shipping
IEP	Integrated Electric Propulsion
IFEP	Integrated Full Electric Propulsion
IMO	International Maritime Organization
INSA	International Naval Safety Association
IPP	Independent Power Producers
ISO	International Organization for Standardization
Kg/m^3	Kilograms per cubic meter
Kt	Knots
kV	Kilo Volt
LNG	Liquefied Natural Gas
LOA	Length Over All
LPG	Liquefied Petroleum Gas
LR	Lloyd's Register
LVAC	Low Voltage Alternating Current
LVDC	Low Voltage Direct Current
MIL-F	Military Specification
MIL-STD	Military Standard
MW	Mega Watt
NATO	North Atlantic Treaty Organization
NM	Nautical Mile
NOPS	Naval Offshore Patrol Vessel
NO_x	Nitrogen Oxides

NSC	Naval Ship Code
NSCA	Naval Ship Code Association
NSD	New Sulzer Diesel
NSSC	Naval Ship Safety Certification
OPV	Offshore Patrol Vessel
P	Power
PMD	Paraffinic Middle Distillate
POD	Podded Azimuth/Azipull thruster
PTI	Power Take In
PTO	Power Take Out
PV power plant	Photovoltaic power plant
RINA	Registro Italiano Navale
RPM	Revolutions Per Minute
SAR	Search and Rescue
SFOC	Specific Fuel Oil Consumption
SOLAS	Safety of Life at Sea
SO_x	Sulphur Oxides
SPD	Hydro Processed/Hydro Treated Renewable Diesel
STANAG	Standard Agreement
t	Tonnes
TL	Türk Loydu
U.S.	United States
UK	United Kingdom

1 INTRODUCTION

This thesis is made for Wärtsilä Oyj Abp. Wärtsilä produces comprehensive machinery and energy solutions globally for maritime and energy industry. Wärtsilä's expertise also includes naval power plant solutions and the focus of this thesis is to explore the modern engine and machinery configurations as conventional machinery replacement.

The topic of the thesis is based on the need of renewal the aging European naval fleet since the defence policy situation has changed significantly in Europe over the last five years.

Future naval and Border/Coast Guard vessel new buildings will have the opportunity to use new technology-based machinery systems that can offer the same output power in more environmentally friendly and energy efficient way.

The scope of the review will be the European countries' Destroyers, Frigates, Other vessels including Amphibious, Helicopter carriers, Assault, Combat Support Ships and Coast/Border Guard vessels which are suitable by their size and previous machinery solutions for the products of Wärtsilä. On the basis of information available at the time this thesis is being written, I will study present and previous machinery solutions to find out what kind of machinery systems could be possible to use in different classes of naval and Border/Coast Guard vessels in the near future.

1.1 Objectives and research questions

The aim is to find out if power-to-weight ratio in modern medium speed diesel engines is good enough to outdate traditional gas turbines and high-speed diesel engines in naval vessels as well as to explore the use of alternative fuels and hybrids on warfare and Border/Coast Guard vessels.

The preliminary research problem is the question if modern medium speed diesel engine configuration with all of its modern auxiliaries is a better option to Navy and

Coast/Border Guard vessels compared with traditional diesel engines and gas turbine combination?

The research problem can be divided into the following parts:

- Is it possible to achieve same speed requirements with modern medium speed diesel engine as with gas turbine (over 30 knots) in present vessel classes
- Medium speed diesel engine space requirements Vs. gas turbine
- Service costs in modern medium speed diesel engine compared with gas turbine
- Fuel consumption in modern medium speed diesel engine compared with gas turbine, the effect on the operating range of the vessel
- Comparison between diesel-electric and direct driven propulsion systems, benefits and disadvantages of both systems
- Hybrid application suitability in Navy and Coast/Border Guard vessels
- What kind of benefits and disadvantages would hybrid application give
- What kind of alternative fuels could be used in future Navy or Coast/Border Guard vessels

1.2 Demarcation

Information obtained to this thesis is limited to public internet sources due to the classified information within military industry that is not available or can not be used as source of information.

1.3 Previous studies

I did not find any similar thesis or research publications in Bachelor's Theses and publications pool -Theseus nor anything similar to this topic on internet publications. Several thesis and research publications which were related to hybrid applications in ships and for the use of alternative fuels were found.

1.4 Research method

Applied research was formed to be the research method. This thesis is entirely theory-based as it aims in finding out if surface combatant ships are going to have bigger machinery lay-out chances in the near future. The purpose of this thesis is also to find out what types of ships modern technology is suitable to apply to.

Information is acquired on the basis of the author’s work experience, discussions with machinery manufacturer and with personnel working on Finnish Navy “laivue 2020” -project.

2 SUBSCRIBER OF THE THESIS

2.1 Wärtsilä Oyj, Abp

Wärtsilä was established 1834. The company's core business was sawmill industry. In 1850 the same owner, Nils Arppe founded Värtsilä's Ruukki and after he passed away his heir merged Wärtsilä sawmill and Värtsilä Ruukki in 1907 to Oy Wärtsilä Ab. (Wärtsilä history, 2018).

During the 1930s recession the company was in bad economic situation but the CEO Wahlforss managed to restructure the company again by negotiating a significant salary reduction and by buying the company "Kone- ja Siltarakennus OY". Aforementioned acquisition was the most significant during the 1930 in Finland and because of it Wärtsilä began working in the shipbuilding industry, paper machine manufacturing and in locksmith industry. (Wärtsilä history, 2018).

In late 1930's Wärtsilä bought licence to Krupp diesel engines and started to manufacture diesel engines only for their own shipbuilding industry and by the early 1960's Wärtsilä manufactured their first own commercial designed diesel engine -Wärtsilä Vasa 24. (Wärtsilä history, 2018).

Between 1965 and late 1980's after numerous acquisitions in various industries like porcelain-, glass-, locksmith and marine diesel engine companies, Wärtsilä's dockyard part went bankrupt due to the competition from the Asian dockyard business. Rest of the Wärtsilä was merged with diversified industry company Oy Lohja Ab and a new company Metra Oy was born. (Wärtsilä history, 2018).

After several acquisitions of smaller diesel engine manufacturer like Stork, NOHAB and SACM, Metra Oyj bought bankrupted Bremer Vulkan's part from New Sulzer Diesel (NSD) in 1997 and rose among the large diesel engine manufacturers. Wärtsilä Diesel (part of Metra Oy) and NSD merged and Wärtsilä NSD was born. In early 2000 Metra Oy who owned Wärtsilä Diesel bought rest of the NSD company from Italy government owner dockyard company Fincantieri. Metra Oy and Wärtsilä NSD was merged after the acquisition and new company was named back to Wärtsilä Oyj Abp. (Wärtsilä history, 2018).

Nowadays, Wärtsilä is an international leader in marine and energy market power solutions which support customers through installations life cycle. Wärtsilä maximizes the environmental performance and economy of ships and power plants by focusing on technological innovations and efficiency. (Wärtsilä, 2018).

In 2018 Wärtsilä had approximately 19000 employees and performed operations in more than 80 countries around the world. (Wärtsilä, 2018).

3 PRESENT NAVY AND COAST/BORDER FLEET IN EUROPE

3.1 Vessel classes

Rapid aging of European Warfare and Coast/Border guard vessel fleet and changes in defence political situation has created the need to modernize the fleet across the European countries. At least Germany, France, United Kingdom and Finland are designing/constructing new buildings or retrofitting already existing vessels. (Global security, n,d).

Since this work is made for Wärtsilä and consider medium speed diesel engines, the vessel classes to be examined were chosen by their suitability for the engines that Wärtsilä manufacture. The following categories of vessels were selected: Destroyers, Frigates, other support vessels including Amphibious assault ships, Helicopter carriers, Combat Support Ships and Coast/Border Guard Offshore Patrol Vessels.

Warfare ships have traditionally been built using almost the same pattern from early 1900's in all vessel classes. The most common engine installation has been a combination of several diesel engines to perform cruising speed and in addition gas turbine/s to achieve the maximum speed when needed.

Appendix 1 lists the present European Destroyers, Frigates, Amphibious, assault ships, Helicopter carriers, Combat support ships and Coast/Border Guard vessels by vessel classes. Basic information such as type/number, owner State, displacement, length, build year, speed, Main Engines output, and range is obtained from the latest 2017-2018 Jane's Fighting Ships which compiles the latest information pertaining to warships and Coast/Border Guard vessels annually, (Jane's Fighting Ships 2017-2018)

The analysis of the above-mentioned appendices reveals that some European countries use different class name out of same warfare ships, for example in Germany a Frigate can be as big as a Destroyer in France. Similarly, Corvettes and Frigates can be equal or even bigger in some cases depending of country that owns the vessel. Corvettes are mostly so small ships that Wärtsilä medium speed diesel engines are not suitable for the class. The latter distinction of vessel classes is based on the division of the Jane's Fighting ships into different vessel categories.

3.2 Technical comparison between present vessel classes

3.2.1 Destroyers

Present Destroyers are the largest combatant warships in size. It is common them to have gas turbine/s in addition to diesel engines which are used as cruising engines but there are some exceptions as well like French Cassard Class with diesel engine installations. Displacement in European destroyers is between 4908 t – 7570 t, LOA between 139 metres – 152,9 metres, beam between 15 metres – 21,2 metres, average age circa 16 years, speed with diesel engines between 18 kt – 29 kt, max. speed between 27,5 kt – 31 kt, diesel engine power output between 4 MW – 31,75 MW, total output between 31,75 MW – 56,95 MW and range between 2500 NM – 8000 NM depending on speed and on the combination (diesel engines or diesel engines + gas turbine) used to produce the speed. (Saunders, 2018).

Picture 1. French Cassard Class Destroyer FS Jean Bart, launched 1986. (Wikipedia, 2018)

- 4 SEMT-Pielstick 18 PA6 V280 BTC Diesel engines, 31,75 MW
- LOA 139 metres
- Beam 15 metres
- Speed 29,5 kt
- Range 8000 NM at 17 kt
- Displacement 5080 t

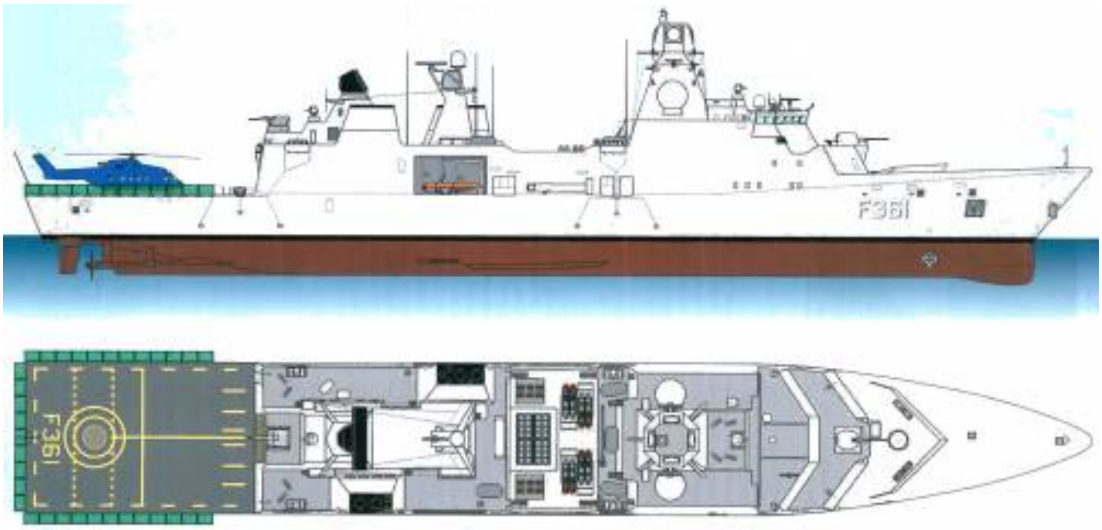
Picture 2. French Forbin Class Destroyer FS Forbin, launched 2006. (Military Factory)

- 2 FIAT Avio/GE LM 2500 gas turbines, 47 MW
- 2 SEMT-Pielstick 12PA 6 STC, 9.4 MW
- LOA 152, 9 metres
- Beam 20,3 metres
- Speed 18 kt with diesel engines, 31 kt with max power output
- Range 7000 NM at 18 kt
- Displacement 6096 t

3.2.2 Frigates

Frigates as a concept is much wider than Destroyers. It is also common in frigates to use combined diesel engines and gas turbines to achieve higher maximum speed in

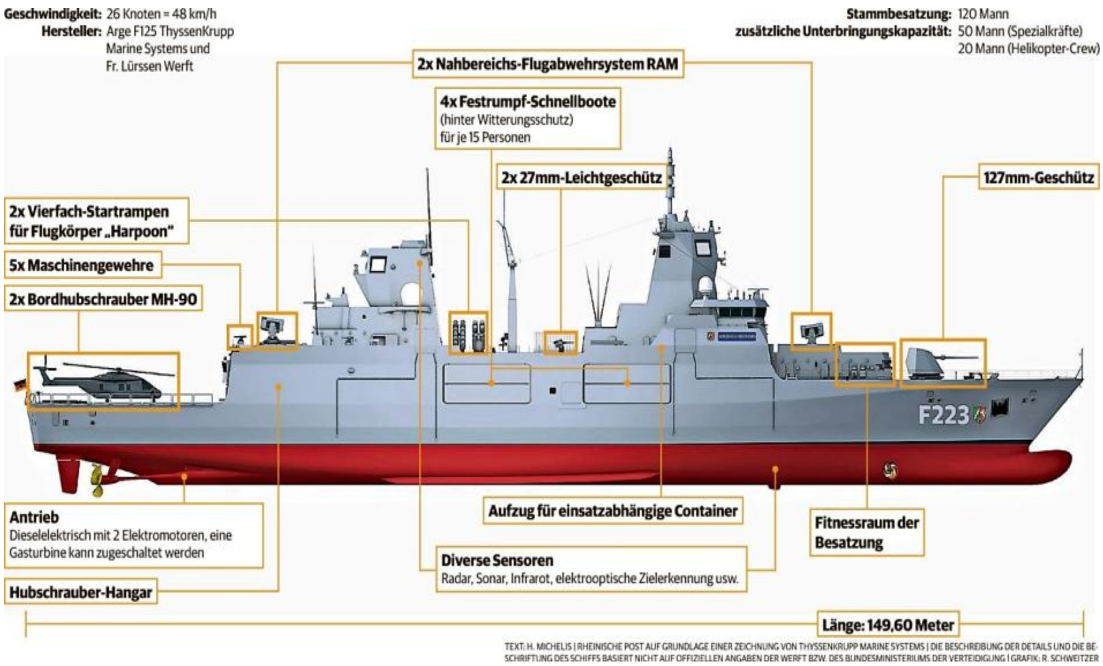
larger ships but the biggest difference compared to Destroyers is that operational range decreases by 30 - 50 % because they often have less fuel. Solely diesel engine powered Frigates have the range between 8000 NM to 10000 NM.
Size scale in Frigate class is much wider, displacement varies between 1270 t – 7136 t, LOA between 80,5 meters – 146,5 meters, Beam between 10,3 meters – 18,8 meters, average age circa 24 years, speed average with diesel engines 20 kt, speed with combined diesel engines and gas turbine/s average 29 kt, diesel engine power output between 5,7 MW – 32,8 MW, total power output between 6,95 MW and 49 MW and range between 4000 NM – 10000 NM. Vessels with combined diesel engine + gas turbine have a range between 4000 NM – 6000 NM with the average speed of 15 kt and vessels with solely diesel engines with traditional propulsion or with diesel electric propulsion system have range between 6000 NM and 10000 NM. (Saunders, 2018).



Picture 3. Danish Iver Huidtfelt Class Frigate HMDS Iver Huidtfelt, launched 2010. (The-blueprints)

- 4 MTU 20V M70 diesels, 32,8 MW
- LOA 138,7 meters
- Beam 19,8 meters
- Speed 28 kt
- Range 9000 NM
- Displacement 6645 t

According to Jane’s Fighting Ships the Iver Huidtfelt Class Frigates is the largest Frigates with solely diesel engine installations. Compared to German Baden Wurttemberg Class Frigate F-222 below, operational range is much bigger with diesel installation compared to a combined diesel and gas turbine installation. In other words what they win in speed, they lose in range. (Saunders, 2018).



Picture 4. German Class 125 Frigate. (Dmitryshulgin, 2015).

- 1 GE LM 2500 gas turbine, 20 MW
- 4 MTU 20V 4000 diesels, 12,06 MW
- LOA 143 meters
- Beam 17,4 meters
- Speed 26 kt with combined diesels and gas turbine
- Range 4000 NM with 18 kt
- Displacement 7136 t

Difference in distance between the two Fregates above is not fully comparable since in range information, 9000 NM in Iver Huidtfelt, no speed indication has been announced. Presumably, the speed is cruising speed and somewhere between 15 - 18 kt. (Saunders, 2018).

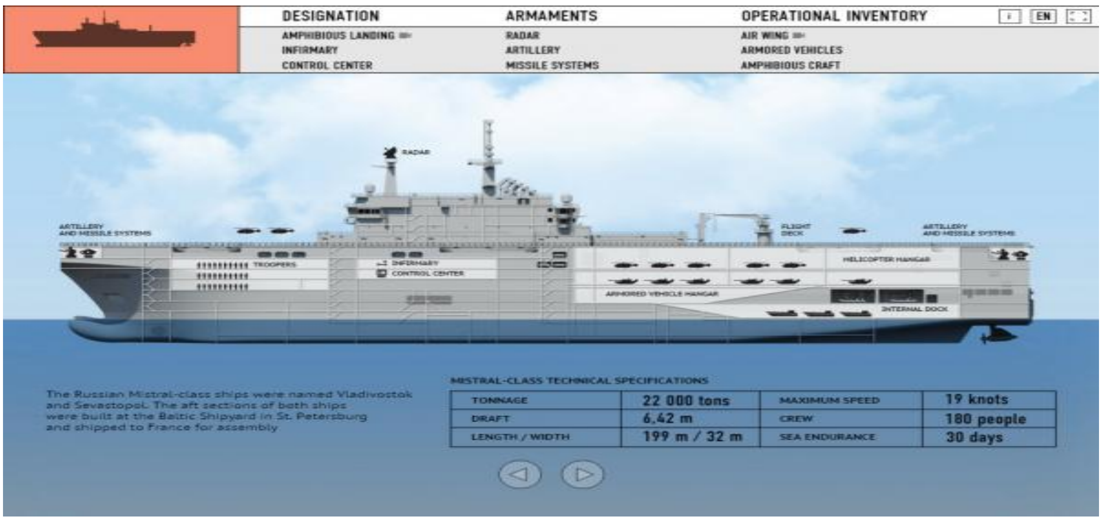
3.2.3 Other vessels including Amphibious assault vessels, Helicopter carriers and-Combat support ships

Most of the “Other Ships” -class installations in Europe is diesel or diesel electric installations. Vessels is used as support ships so their speed requirements are lower but the size and range is bigger. The exception are UK owned Albion Class and French Mistral class which are assault ships but according to installations suitable for medium speed four stroke diesel-engines.

The “Other vessels class” consists of the following types of vessels: 2 Danish Combat support ships with 2 MTU 8000 M 70 diesels, launched 2004 (16,63 MW, LOA 137 metres, beam 19,5 metres, maximum speed 23 kt, range 11500 NM with 14 kt, displacement 6401 t). Amphibious ships (power output between 9,2 MW – 36,6 MW, LOA between 160 meters – 202,3 metres, beam between 25,2 metres – 32 metres, speed between 17 kt – 21 kt, range between 6000 NM – 11500 NM depending on speed, displacement between 10668 t – 27514 t, average age 12 years). UK owned helicopter carrier (2 Crossley Pielstick 12 PC 2.6 V 400 diesels, 13,5 MW, LOA 170 metres, beam 34,4 metres, speed 19 kt, range 8000 NM at 15 kt, displacement 22,107 t, launched 1995) and 2 UK owned Albion class assault ships (2 Wärtsilä-Vasa 16V32E and 2 Wärtsilä-Vasa 4R32LNE diesel engines with 15,6 MW total power output, LOA 176 metres, beam 28,9 metres, speed 18 kt, range 8000 NM at 15 kt, displacement 18979 t which is launched 2001). (Saunders, 2018).

Picture 5. UK Albion Class Assault ship HMS Bulwark, launched 2001. (Pinterest, n,d).

- 2 Wärtsilä-Vasa 16V32E, 2 Wärtsilä-Vasa 4R32LNE, total output 15,6 MW
- LOA 176 metres
- Beam 28,9 metres
- Speed 18 kt
- Range 8000 NM at 15 kt
- Displacement full load 18979 t



Picture 6. Mistral Class Amphibious assault ship, launched between 2004 – 2010. (Durden, 2015).

- 3 Wärtsilä 16V32, 1 Wärtsilä 18V200, total power output 20,8 MW
- LOA 199 metres
- Beam 32 metres
- Speed 19 kt
- Range 11000 NM at 15 kt, 6000 NM at 18 kt

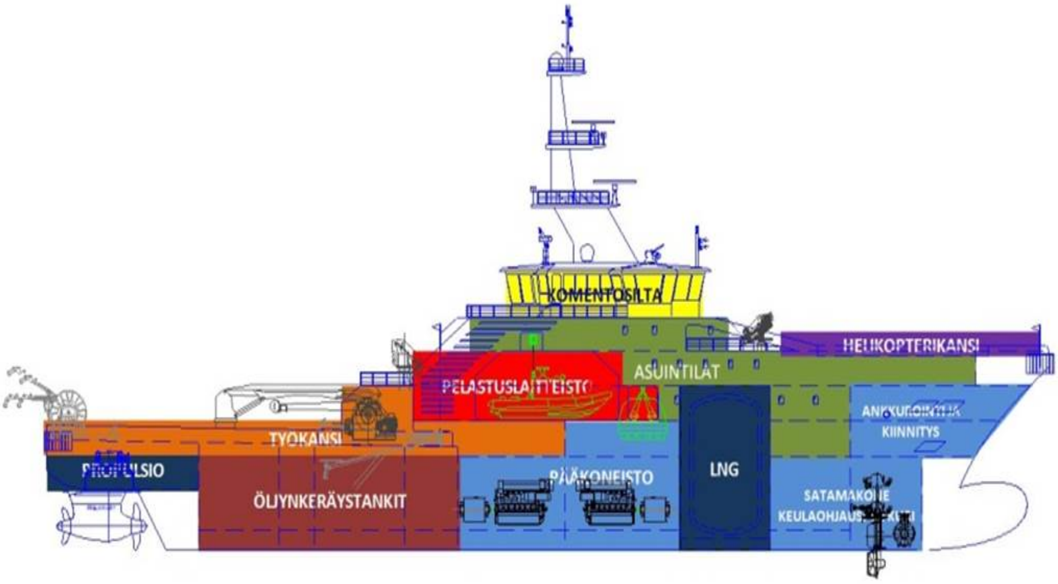
3.2.4 Coast/Border Guard Vessels

Coast/Border Guard vessels differ from warships in machinery lay-out and in hull structure because in many countries they are also used in SAR missions, surveillance, police operations etc. Compartmentation is built different and machinery areas have more space. Operation profile is similar to warships, most of the time vessels patrol in economic speed but sometimes it is also necessary to use full power reserve. Although the national law allows deviation from international emission regulations and ship building rules, Coast/Border Guard vessels are built over the last decade more environment friendly and energy efficient which is normally based on LNG technology.

Machinery installations depends entirely on the shape of the hull and on the desired speed of the vessel. On ice-covered waters, vessels generally have higher total engine power output because ice reinforcements increase the vessel's weight and the need to break the ice increases power demand. In areas where is no need to reinforce vessels or build vessels in lighter ice-class they can be built lighter which decreases the total power need or with the same machinery installation, the range increases.

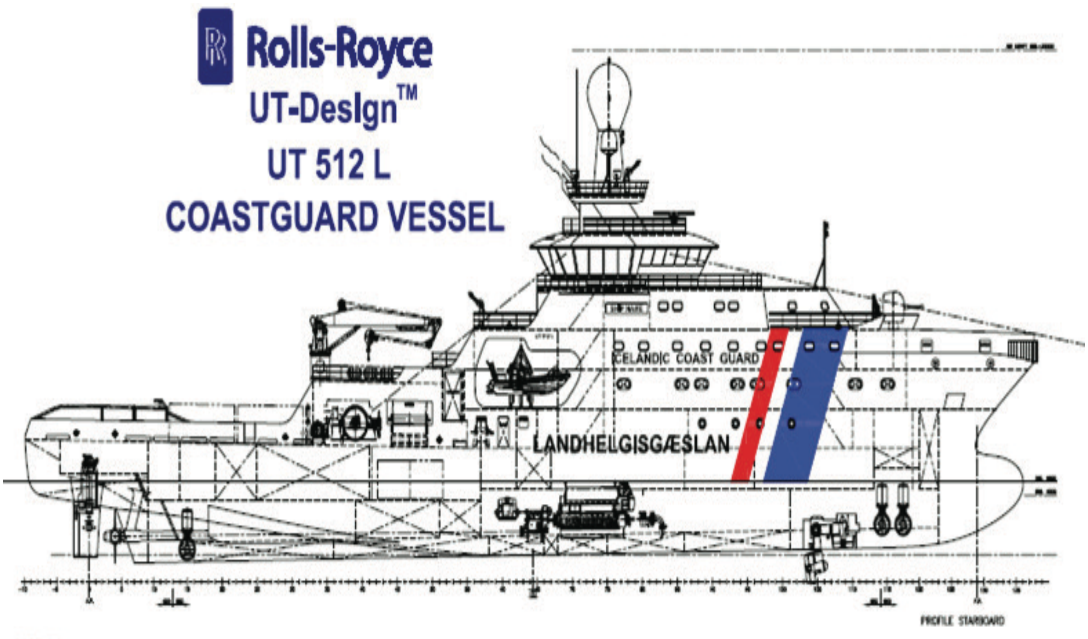
As afore-mentioned, size, lay-out, power demand and range depend entirely of the area where the vessel is planned to operate and therefore the scale of the required characteristics on ships is as large as the following information from Jane's Fighting Ships shows. Displacement in Border/Coast Guard vessels varies between 244 t – 6401 t, LOA between 47,3 metres – 108,4 metres, beam between 7,5 metres – 19.1 metres, average age 20 years, speed between 11 kt – 40 kt and range between 2000 NM to

10000 NM. The average age of these vessels indicates the urgent need to renew these fleets in near future so the markets are growing all the time. (Saunders, 2018).



Picture 7. Finnish Border Guard Vessel Turva, launched 2014. (Laitanen, 2014)

- 1 Wärtsilä 12V34DF (dual fuel, diesel & LNG), 2 6R34DF, 1 6L20DF total power output 12 MW
- LOA 95,8 meters
- Beam 17,7 meters
- Speed 20 kt
- 6000 NM
- Displacement 4600 t



Picture 8. Iceland Coast Guard Thor Class Offshore Vessel Thor, launched 2014. (Icelandic Coast Guard 2014)

- 2 Bergen B 32:40L diesels, total power output 8 MW
- LOA 93,8 metres
- Beam 15,5 metres
- Speed 19,5 metres
- Range, not reported

4 POWER PRODUCTION ALTERNATIVES IN FUTURE NAVY AND COAST/BORDER GUARD VESSELS

4.1 Regulations and Classification rules

The states usually have a written warrant in law regarding warfare and coast/border guard vessels. The Finnish version: "Does not apply Defence Forces and Border Guard" appears almost in law clause that has anything to do with shipbuilding. The clause gives the Finnish naval Administration or other responsible authority the right to deviate from international rules and regulations in ship building and in emission regulations. Nonetheless the States are willing to join in global reduction of emissions and greenhouse gases so countries like Finland have built recently and is designing new buildings according to IMO emission regulations (IMO, 2018). In Europe it is a common habit to build warfare and Coast/Border guard vessels according by some classification society's rules and regulations for naval ships and build the vessels compatible with North Atlantic Treaty Organization (NATO) standards.

The most used code for many NATO and non-NATO combatant and non-combatant ships is in 2009 released NATO ANEP 77 (Allied Naval Engineering Publication). ANEP77 (known also as Naval Ship Code) can be seen as a naval version of IMO SOLAS (International Maritime Organization, Safety of Life at Sea) -convention. The latest version of ANEP77, the Naval Ship Code is edition G, version, released in february 2019. (INSA, 2019).

In the late 1990's several classification societies worked independently with many navies in aim to create naval classification rules. In order to create consistent rules, some of these Classification societies suggested collaboration with NATO's Naval Group 6 and in 2002 The Naval Ship Classification Association (NSCA) was established. Today NSCA is composed of 8 classification societies, Bureau Veritas (BV), Registro Italiano Navale (RINA), American Bureau of Shipping (ABS), Lloyd's register (LR), Türk Loydu (TL), Polish Register (PRS), Det Norske Veritas – Germanisher Lloyd (DNV-GL) and Hellenic Register of Shipping (HRS) and NATO's Naval Group 6. (Safety4sea, 2019).

NSCA started to work on naval safety issues and 2008 an open forum between NSCA and interested countries was established. The International Naval Safety Association (INSA) was established 2013 and currently the NSCA consists of navies from following countries: UK, Norway, France, Sweden, Denmark, Netherlands, Italy, South Africa, Australia, Singapore and Canada. NSCA's main task today is to develop and maintain the Naval Ship Code. (INSA, 2019).

4.1.1 Naval Ship Code Framework

This chapter 4.1.1 "Naval Ship Code Framework" is written on the basis of Naval Ship Code 2014. ANEP77 is a naval surface ship safety code based on IMO conventions that are applicable for government vessels. It is a goal-based standard which is intended to work as a tool in design, construction and during ship operation in non-commercial conventional powered government ships like navy, coast guard, border patrol, customs ships.

As aforementioned, governments have their own national regulations and it is not mandatory to use the naval ship code but any nation is free to use the entire code or part of it if necessary in designing, constructing or operating the ship. In case the code is used, it requires that a Concept of Operations Statement (ConOpS) is developed. It defines characteristics, function and operational areas of the ship. The purpose of ConOpS is to compare the suitability of the selected standards and criteria if for example only parts of the code is chosen. This creates the foundation for NSC Certification. ConOpS can change several times during the project if necessary.

The naval ship code includes three parts, NSC Requirements, Solutions and Justification/Guidance. Each part contains the same Chapters:

Chapter 0: Using the Naval Ship Code Chapter
Chapter I: Naval Ship Safety Certification
Chapter II: Structure
Chapter III: Buoyancy, Stability and Controllability

Chapter IV: Engineering Systems

Chapter V: Seamanship Systems

Chapter VI: Fire Safety

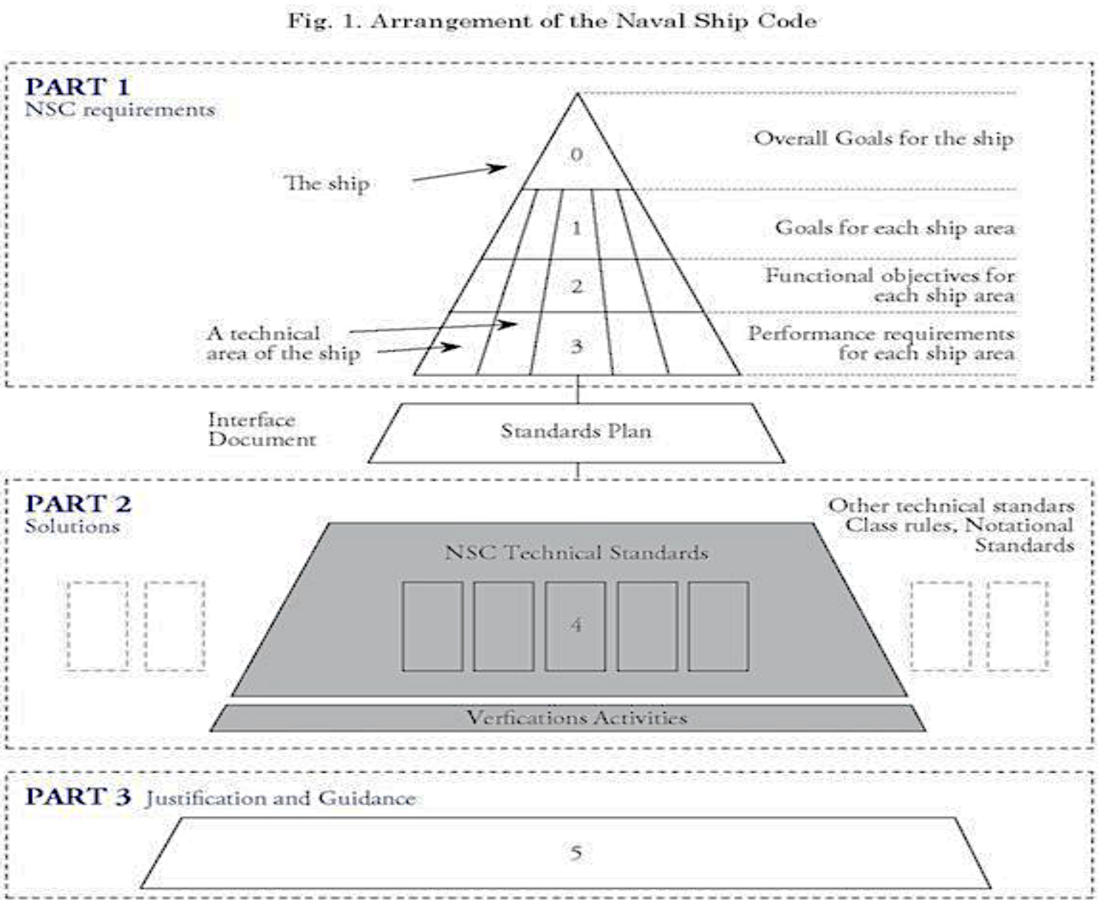
Chapter VII: Escape, Evacuation and Rescue

Chapter VIII: Communications

Chapter IX: Navigation

Chapter X: Dangerous goods

4.1.2 Arrangement of the Naval Ship Code



Picture 9. Framework of NSC. (Ship Science & Technology, 2017)

Part 1, NSC requirements, give instructions for overall goals, how the ship is to be designed, built and maintained within the determined ConOpS. The aim is to operate the vessel safety and to prevent injuries onboard. Governments or naval Administrations may add additional goals determined in ConOpS but all risks must be kept as low as possible.

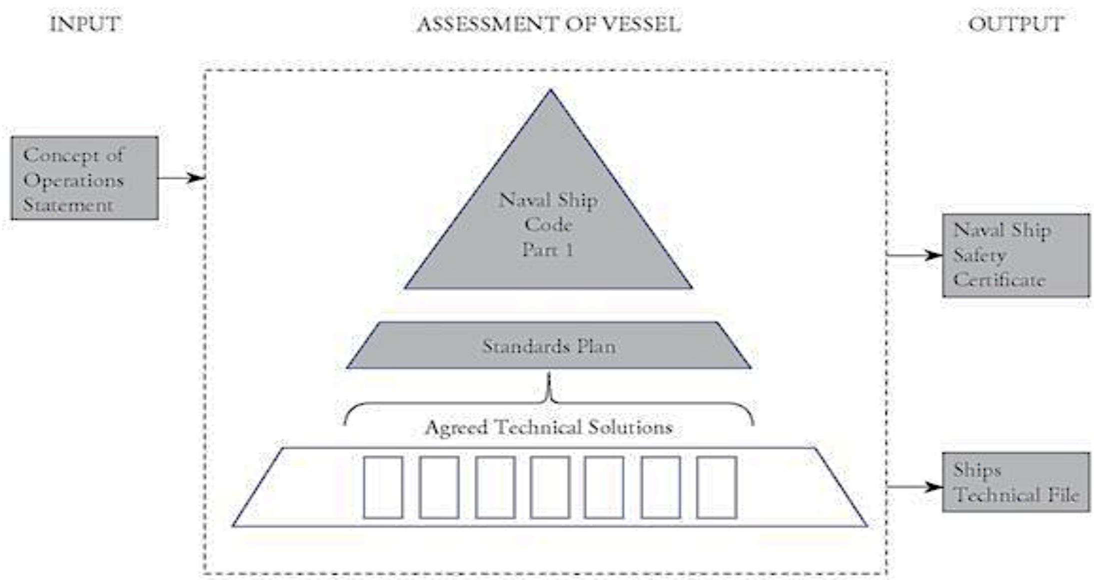
Part 2, Solutions, focuses on suggesting performance capability requirements and solutions of the functional objectives like safe usage of survival crafts and its performance requirements, sea rescue missions and evacuating of big number of persons to another vessel. Part 2 is more detailed than Part 1 and its instructions come directly from IMO regulations.

Part 3, contains justification and guidance like requirement sources from IMO and classification societies. It also provides references data and history from INSA navy members and other parties involved.

4.1.3 NSC certification main regulatory elements

The NSC certification consist of the basic elements, ConOpS as input, NSC as assessment of the vessel and Naval Ship Safety Certificate/Ships Technical File as output.

Fig. 2. Main Regulatory Elements in the Certification Process of Ships



Picture 10. Main regulatory elements in the certification process of ships. (Ship Science & Technology, 2017)

The ConOpS as an input that contains following technical specifications:

- *Mission or roles of the ship*
- *Dimensions*
- *Displacement measures*
- *Speed and endurance*
- *Post damage capability*
- *Operational area*
- *Crew description*
- *Environmental operational limits including navigation in ice*
- *NSC related engineering equipment like propulsion/machinery.*
- *Fire safety systems and gear*
- *Communications and navigation equipment*
- *Maintenance and survey schemes*
- *Etc.*

The assessment of the vessel contains the NSC and is a tool to manage the project and to ensure that the vessel is built basing on best practises and experiences.

Outcome of the aforementioned is that the vessel is certified (Naval Ship Safety Certification -NSSC) by naval administrations or its recognized organisations and technical file of the ship is created. Every new ship shall have a technical file where the application of the code has been described. When the process is completed, the NSSC becomes part of the technical file. If the vessel is modernized or modifications is made, the technical file must be updated and accepted in naval administrations or in its recognized organisation such as classification society. Technical file may include the following information:

- *A copy of ConOpS*
- *Applicable NSC Parts/Chapters being invoked*
- *Applicable NSC Tier level being invoked*
- *The complete Standards plan*

- *Interpretations/Justifications made during the NSC certification process*
- *Classification Society information such as rules, notations, etc.*
- *Statutory certificates*
- *Other information needed*

4.2 Utilization of optional technologies

After studying different types of war ship machinery, the conclusion that naval surface combatant high speed vessels are traditionally built with CODAG lay-out. The development of energy production technology and the desire to produce energy more environmentally friendly has apparently woken the naval Administrations to ponder if traditional machinery and/or propulsion lay-out in these vessels could be implemented in some other way by utilizing modern technology. The power requirement difference between cruising/patrol speed and full speed is substantial since doubling the speed with same hull requires multiple amount of power output. The aforementioned factor along with the speed requirements is not easily solved and naval Administrations have hesitated to obtain a completely new kind of machinery/propulsion lay-out. (Saunders, 2018).

Amphibious vessels, helicopter carriers, assault ships, combat support ships and Coast/Border guard vessels seem to be excellent new technology applications since the power requirement difference between cruising/patrol and full speed is minor and low power required operations can be conducted without running diesel engines on low load.

4.3 Comparison between medium speed diesel engine, high speed diesel engine and gas turbine in naval ships

High-speed diesel engines combined with gas turbine/s has traditionally been used in combat vessels because their compactness, low weight and high power-to-weight ratio. The main disadvantages of these engine types are high fuel consumption, maintenance requirements and high fuel requirements. Fuel consumption (SFOC) difference between medium speed diesel and high-speed diesel/gas turbine is significant and lower fuel consumption means automatically longer vessel operating time. The table below shows the differences in fuel consumption between these engine types.

The following calculation formula has been used to convert g/kWh to L/h:

$$Cl = c \times P \times 1/ro$$

Cl is Consumption in liters, c is consumption in g/kWh, P is Power in kW and 1/ro is fuel density. Power factor in medium and high-speed diesel was chosen to be between 4000 to 5000 kW. Fuel density was chosen to average 0,835 kg/m^3. Fuel consumption is calculated on 85% load in diesel engines. (online conversion, n,d).

Table 1. Specific Fuel Oil Consumption (SFOC) comparison between Wärtsilä 8V31, TIER II medium speed diesel engine with 4880 kW, MTU 20V4000M93L high-speed diesel engine with 4300 kW and Rolls-Royce MT7 gas turbine with 4500 kW. (Wärtsilä, 2019) (MTU, 2018) (Rolls-Royce, 2012).

Engine type	Fuel consumption (SFOC) g/kWh at ISO conditions	L/h
Wärtsilä 8V31 TIER II, medium speed diesel engine	167,7 g/kWh	980
MTU 20V4000 M93L, high speed diesel engine	220 g/kWh	1133
Rolls-Royce MT7 gas turbine	243,2 g/kWh	1311

The hull form, especially in frigate -class vessels is very hydrodynamic and it sets restrictions in engine spaces both in width and height direction. Non-combatant vessel types have different type of hull shape which enables capacious engine spaces.

In table below compared dimensions and weight comparison between same engines as in table 1.

Table 2. Dimension and weight comparison between Wärtsilä 8V31 medium speed diesel engine (Wärtsilä, 2018), MTU 20V4000 M93L high-speed diesel engine (MTU, 2018) and Rolls-Royce MT7 gas turbine. (Rolls-Royce, 2018).

Dimensions/weight	Wärtsilä 8V31	MTU 20V4000 M93L	Rolls-Royce MT7
Length (mm)	6067	4015	1500
Width (mm)	3115	1470	877
Height (mm)	4701	2440	877
Weight (t)	53	12	0,44

4.4 Fuel alternatives

NATO standard F-75 and F-76 define the characteristics of the approved fuel, storage period and handling very accurately. MIL-F-16884 is a specification of naval Distillate for standard F-76 which includes International Standardization Agreements NATO STANAG 1135 -Interchangeability of fuels, lubricants and associated products in NATO. STANAG 1385 defines minimum quality standards for F-75 and F-76 fuels. (NATO, 2018).

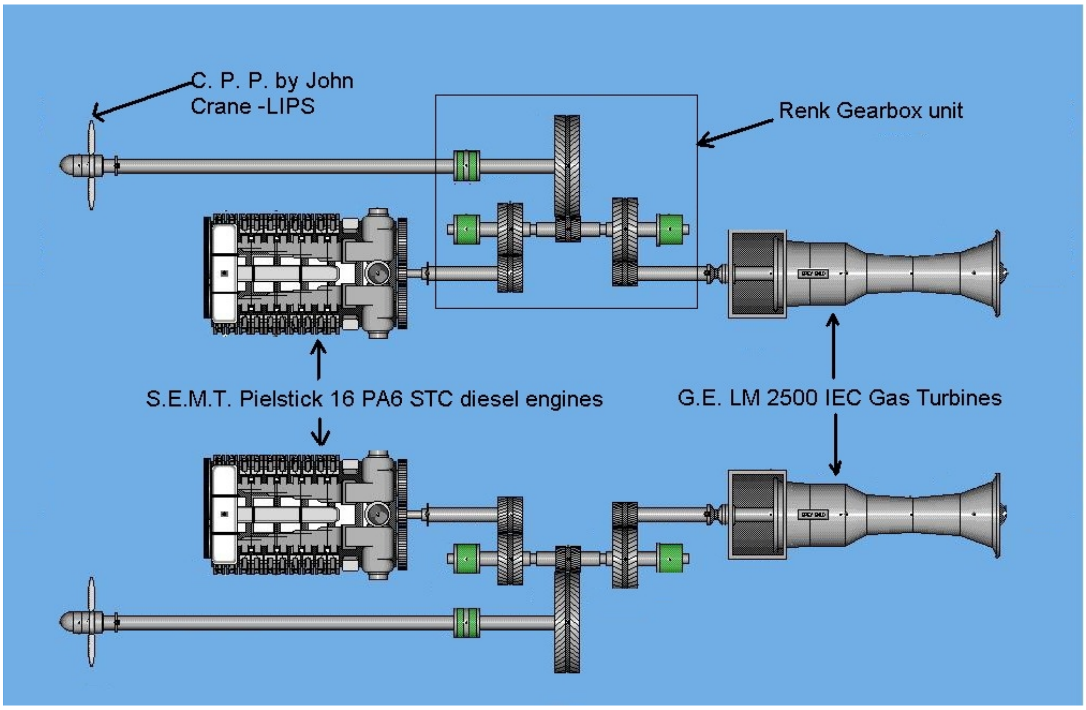
U.S Department of Defense has been a pioneer in the exploration of alternative fuels in military use for the past decade. Long-term storage time and emissions seems to have big role in the research. In the latest MIL-F-16884 N version, following alternative fuels has been added to specifications as approved fuels for navy applications: Fischer-Tropsch Hydro processed Synthetic Paraffinic Diesel (FT-SPD), Hydro processed Esters and Fatty Acids (HEFA), Hydro processed/Hydro treated Renewable Diesel (HRD), Synthesized Paraffine Diesel (SPD) and PMD stands for Paraffinic Middle Distillate. (Everyspec, 2014).

According to F-76 NATO standard, LNG (Liquid Natural Gas) is not allowed as fuel in NATO ships since it is not listed in MIL-F-16884 specifications, but as Naval Ship Code ANEP77 allows, nations can deviate from instructions as Finland did in 2014 when constructing a new non-combatant Offshore Patrol Vessel Turva for Finnish Border Guard. Biggest issue with LNG contrasted to F-76 is the low flash point which in LNG is -188º Celsius compared to traditional fuel oil with flash point + 60º Celsius which is the minimum for NATO approved fuel. LNG as a low emission fuel has found place in Coast/Border Guard fleets around the world in non-combatant vessels. (Bartis & Van Bibber, 2011).

4.5 Propulsion configuration options

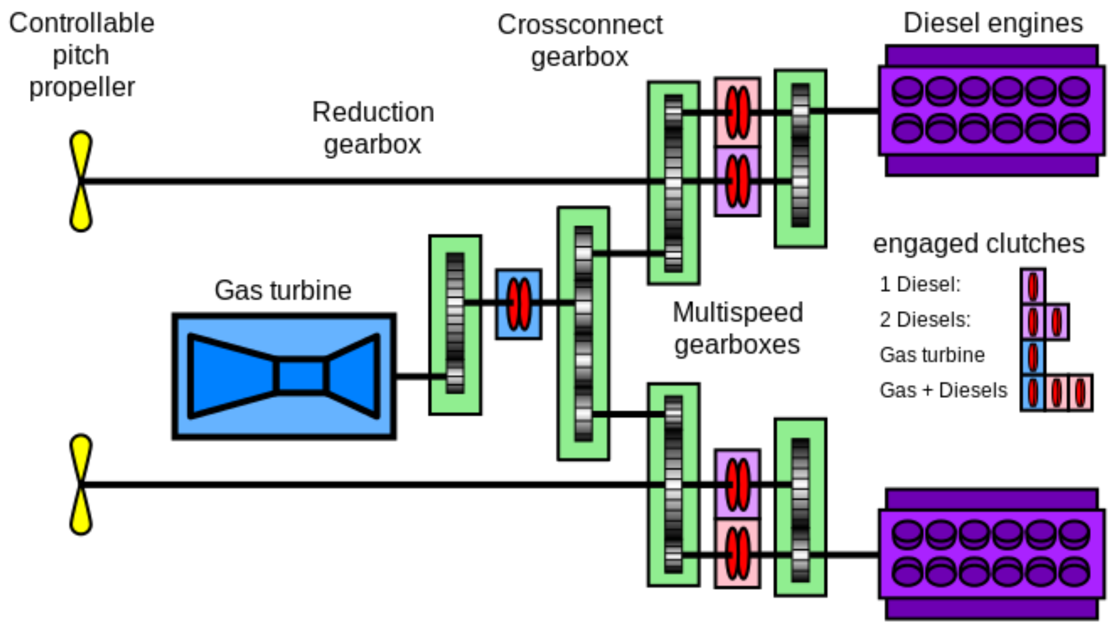
Navy ships have many different installed hybrid propulsion types around the world like CODOG (combined diesel or gas), CODAG (combined diesel and gas), CODLAG (combined diesel electric and gas), CODLOG (combined diesel electric or gas), CODAD (combined diesel and diesel), COSAG (combined steam and gas), COGOG (combined gas or gas), GOGAG (combined gas turbine and gas turbine), COGAS (combined gas and steam turbines), CONAS (combined nuclear and team propulsion system), CODAC-WARP (Combined Diesel and Gas – Water jet and Refined Propeller), IEP (integrated electric propulsion) including FEP (full electric propulsion) and IFEP (integrated full electric propulsion). (Saunders, 2018).

The most common types of the aforementioned propulsion types in European Navy vessels are CODOG, CODAG, CODLAG, CODLOG, CODAD, IEP (including FEP and IFEP) according to Jane’s fighting ships 2017-2018. Rest of the hybrid propulsion types are mostly used in big warfare like Royal Navy’s Country -class destroyer with COSAG, Dutch Navy Korteaner -class frigates with COGOG, Royal Navy’s Invincible -class aircraft carrier with GOGAG, US Navy Arleigh Burke -class destroyers With COGAS and Russian Kirov -class guided missile cruisers with CONAS propulsion. (Saunders, 2018).



Picture 11. CODOG hybrid propulsion in Indian Navy Frigate Shivalik class. (Maxdefense, 2013)

In CODOG hybrid propulsion one diesel engine produces the cruising speed and gas turbine is used to produce the maximum power output to C.P.P (controllable pitch propeller) via reduction gearbox. The characteristic of this hybrid propulsion is that it is built with two separate units, one to each propeller and it cannot use combined power output to both. Advantage of CODOG is a simple gearing but it needs powerful or additional gas turbines since diesel engines must be disengaged when operating gas turbine. CODOG propulsion arrangement is very common in frigates and corvettes. (Global security, n,d).



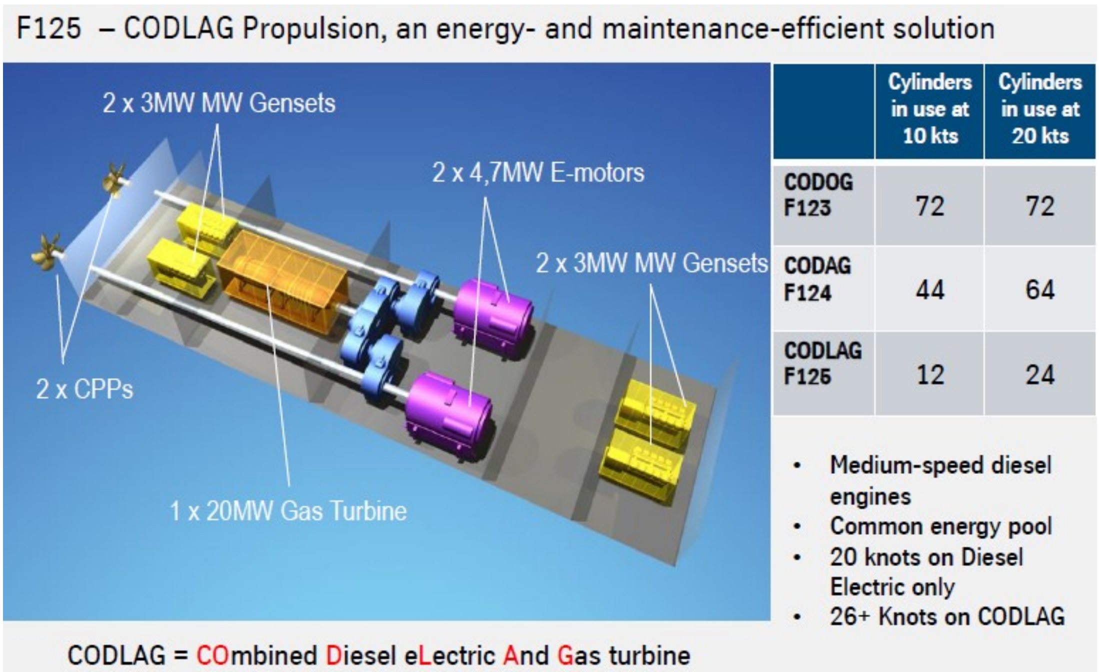
Picture 12. The principle CODAG hybrid propulsion system. (Wikipedia, CODAG, 2018)

In a CODAG hybrid propulsion system two diesel engines are producing the cruising speed and otherwise, like in GODOG -system, diesel engines and a gas turbine can be operated parallel. However, a complex and expensive multispeed cross connect gear-box is mandatory. Diesel engine gear ratio must be changed when operating with both diesel and gas turbine because otherwise the CPP's rpm would get too high. (Wikipe-dia, 2018).

The CODAG hybrid propulsion system is used in Norwegian Fritjof Nansen -class and in the Royal Navy of the Netherlands De Zeven Provencien -class frigates. The con-struction of CODAG -system is suitable for medium speed diesel by the size and weight, the engine installation in De Zeven Proviencen -class is 2 x 16V26 Wärtsilä medium speed four stroke diesel engines. In Fritjof Nansen -class the constructing au-thorities have chosen Bazan Bravo 12V, 4500 kW, no additional information found but the assumption is that Wärtsilä engines 12V26 (4080 kW, weight 29 t) and 8L32 (4640 kW, weight 43,4 t) could be replacement engine types. (Naval Technology, n,d).

One option in CODAG hybrid propulsion could be to install bigger diesel engines and smaller gas turbine since the engine size and weight in medium speed diesel engines does not increase significantly if bigger engines would be installed. The possibility to use simultaneous alternative drive sources in CODAG arrangement allows changes in engine configurations. The benefits of this would be higher cruising speed, lower fuel consumption, bigger range and less emissions since emission regulations do not concern gas turbines.

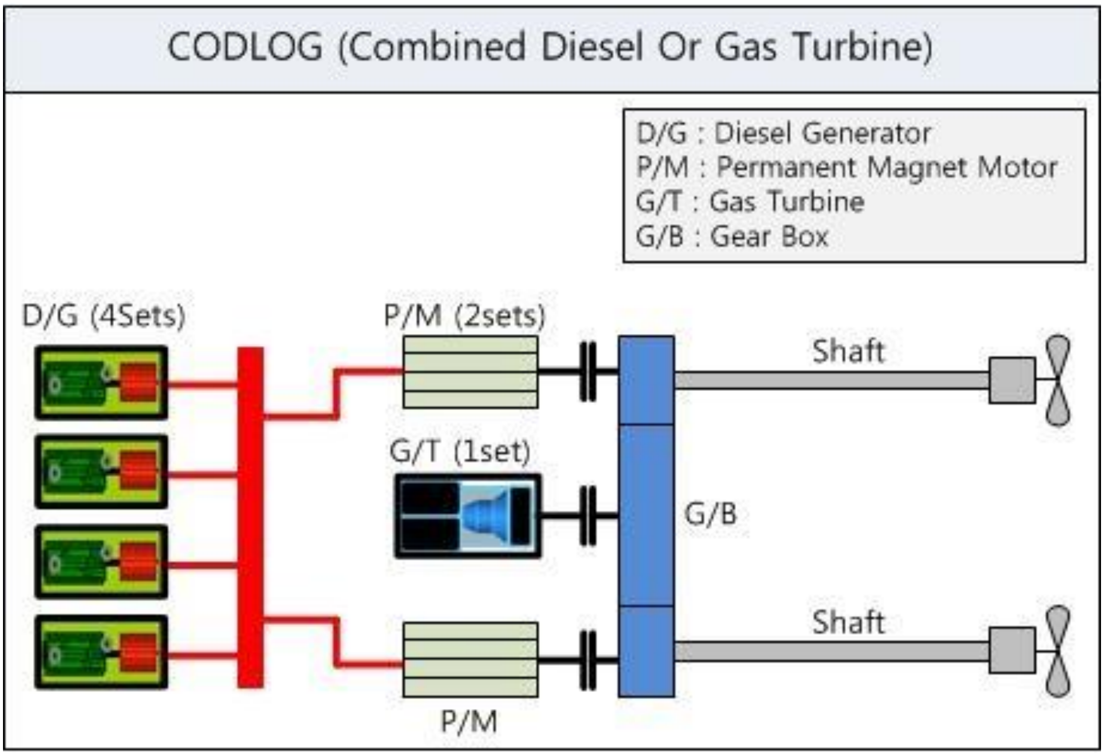
CODAG propulsion has several variations like CODAG-WARP (combined diesel and gas + water jet and refined propeller) and CODAGE (combined diesel and gas electric). CODAG-WARP differs from normal by using two diesels in CODAD arrangement and gas turbine uses centerline water jet. In CODAGE system the two different engine types (diesel and gas turbine) drive the propellers electrically. CODAGE system resembles CODLAG propulsion. (RENK, n.d).



Picture 13. F-125 -class Frigate CODLAG propulsion arrangement. (Wordpress, 2018)

In CODLAG propulsion electric motors run propellers. Cruising speed is achieved with diesel generators and maximum speed with gas turbines. CODLAG arrangement has several advantages: diesel generators can be placed freely in engine department, more engine/generator sets are available when choosing the engine type to new vessel, less noise is generated since diesel generators can be decoupled from the hull of the ship, gearbox is much simpler and service costs are lower since electric motors require less maintenance.

The diesel engine lay-out in CODLAG arrangement can be modified in many ways, for example by reducing the number of engines to two medium speed diesel engines and to one harbor generator. This would reduce services costs even more and at the same time the cruising speed would decrease and even the operating range would increase because of lower fuel consumption. (Revolvy, n.d).



Picture 14. FREMM -class frigate CODLOG arrangement. (Buckingham, 2018)

CODLOG arrangement is a variant of CODLAG where the arrangement and the basic elements are the same but it doesn’t allow the use of simultaneous alternative drive sources.

Vessels with CODLOG arrangement like German F-125 -class with four MTU 20V 4000 M53B diesel engines (total diesel engine power output 12.06 MW) and French FREMM -class with four MTU 16 V 4000 M63 L diesel engines (total diesel power output 8.96 MW), the diesel engines produce propulsion power in cruising speed. Gas turbine produces the propulsion power output when speed above cruising speed is needed. CODLOG is also a highly modifiable machinery lay-out. (Jane’s, n,d) (sea-forces, n,d) (ipfs, n,d)

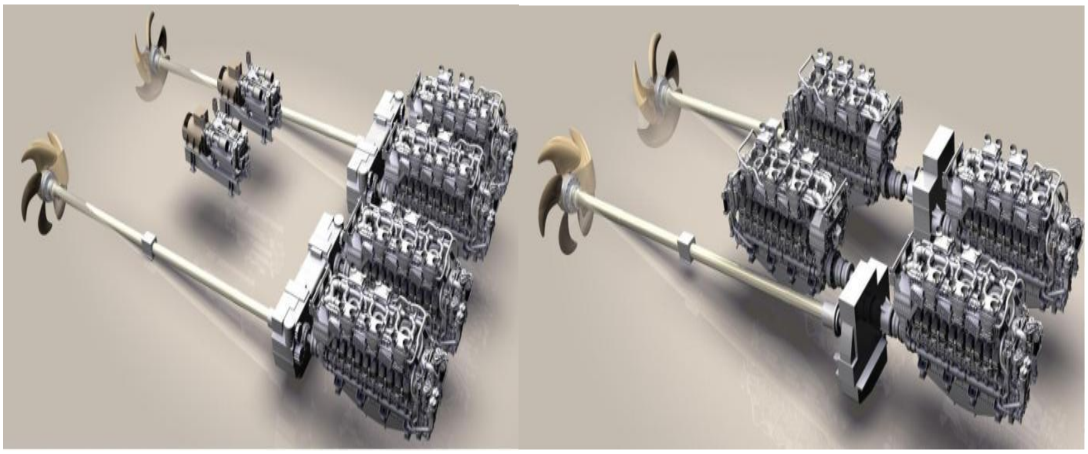
Table 3. Comparison between FREMM, MTU 16V 4000 DS 2250 (MTU, 2018) and F-125, MTU 20V 4000 DS (MTU, 2018) frigates genset dimensions and Wärtsilä's nearest genset dimensions based on the power output. (Wärtsilä, 2018) (MTU onsite energy, n,d).

Specifi-cations	**MTU 16V 4000 DS 2250 Genset**	**MTU 20V 4000 DS 3250 Genset**	**WÄRTSILÄ 6L26 Genset**	**WÄRTSILÄ 6L32 Genset**	**WÄRTSILÄ 8V31 Genset**
Length (mm)	5090	6654	7500	8505	9100
Width (mm)	1836	1810	2300	2490	3110
Height (mm)	2330	2332	3033	3745	4880
Weight (T)	12,9	19,6	35	57	90
Power output (kW)	1798	3490	1870	3230	4225

As shown in table 3 above, dimension differences are not so big between the engine types and by their dimensions, medium speed diesel engines could be used in vessels of equal size as F-125 and FREMM. The biggest difference is the weight of the engines. Medium speed diesel engines weight approximately 2,5 times more compared to high-speed diesel with the same power output.

On the other hand, the maintenance interval of a four-stroke machine is longer because of a more massive structure, whereas in the worst-case high-speed diesel engine has to be replaced entirely by a new machine when the specified number of running hours is reached. A four-stroke medium speed diesel do not need to be replaced during the life cycle of the ship.

Gensets in F-125 have a total weight of 78,4 tons. If engine configurations had been implemented with medium speed diesel engines, the weight had been approximately 214 tons (2 x Wärtsilä 12V32 and 1 x 4L20) and it is a factor that affects machinery selection.



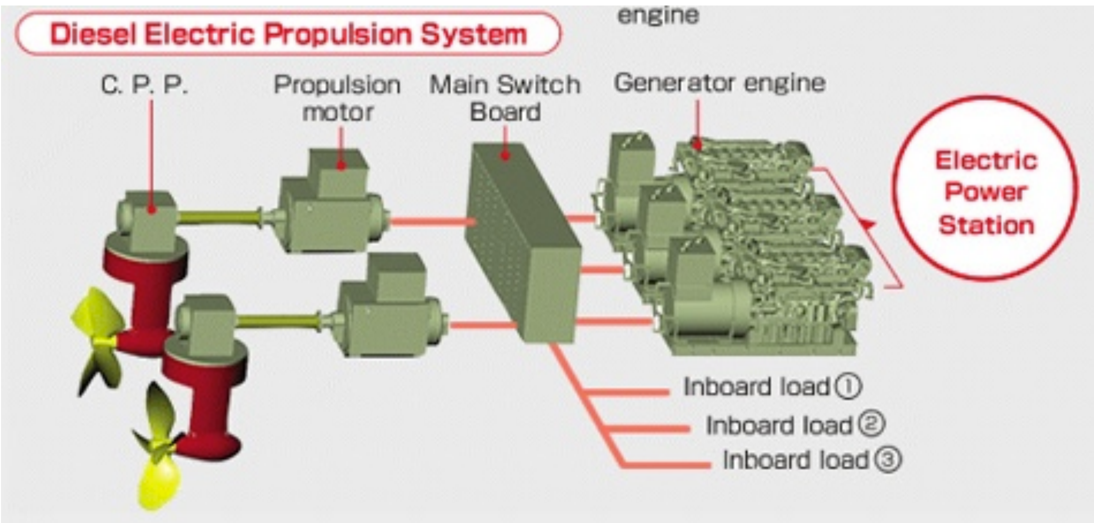
Picture 15. CODAD U-arrangement on the left and T arrangement on the right. (Ohmayer, 2012)

CODAD propulsion system is based on only diesel engines and there are many variations like U-arrangement and T-arrangement. The Danish frigate “Iver Huitfelt” is a CODAD vessel equipped with four MTU 20V8000 diesel engine, 8.2 MW each. With total power output of 32,8 MW the vessel reaches top speed of 30 kt. Speed of “Iver Huitfelt” -class is very comparable with vessels equipped with gas turbine installations. Vessels with CODAD propulsion have recently been built to some European countries. Asian countries like Malaysia, Singapore and China have, according to several publications in the internet shown interest to solely diesel engine arrangement. Navies around the world follow closely what kind of naval ships their “competitors” build and it is possible that this fact can create a positive contribution to the future construction of vessels with CODAD arrangement. (Defence database, n.d).

Table 4. Comparison between the dimensions of MTU 20V8000 (MTU online, 2018) and Wärtsilä's nearest medium speed diesel engine, based on the power output. (Wärtsilä Solutions, 2017).

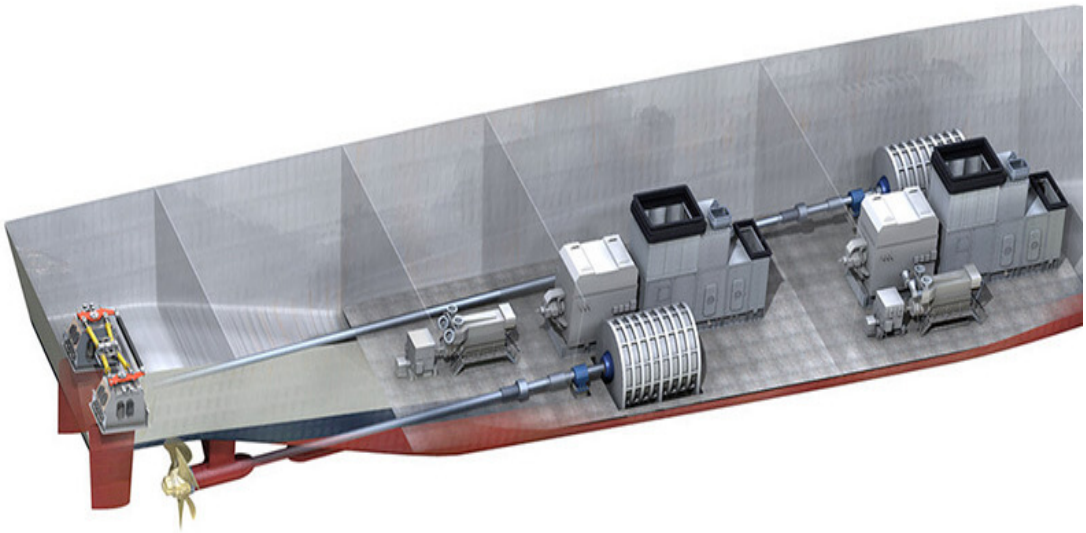
Specifications	MTU20V 8000 M71	Wärtsilä 16V31	Wärtsilä 16V32
Length (mm)	6645	9130	8060
Width (mm)	2040	3500	3020
Height (mm)	3375	4156	3905
Weight (t)	45,3	89	74,1
Power Output (kW)	8200	9760	9280

As it can be seen in the table above, the biggest difference is in the engine weight. Space requirement is bigger in medium speed diesel engines but according to engine type comparison in table 3 and 4, it is not that big. Another big component that restricts the engine room space is gearbox/gearboxes which can be quite big in size depending on the chosen propulsion installation type.



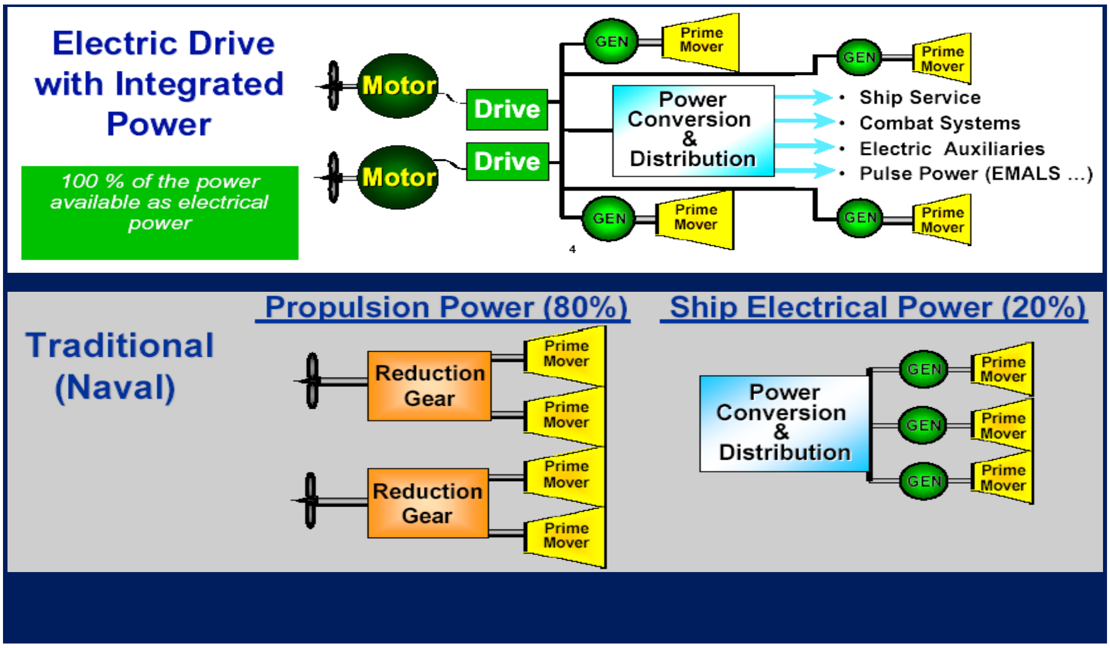
Picture 16. Integrated electric propulsion, IEP. (EastWest Marine Consulting, 2018)

The difference between IEP (Integrated electric propulsion) and CODLAG propulsion systems is that in IEP, the gearbox is not included in the system. By eliminating the gearbox, a substantial reduction of needed space is achieved. Other benefits of IEP propulsion are lower noise level and free placing of engines. The IEP propulsion system can be divided into three systems: IEP, FEP (full electric propulsion) and IFEP. (Integrated electric propulsion).



Picture 17. The Royal Navy's Type 45 destroyer FEP propulsion lay-out. (Save the Royal Navy, 2016)

The FEP propulsion system is suitable for big warships like destroyers, aircraft carriers, multipurpose amphibious assault ships and in other navy special vessels. Large medium speed diesel engines are used to produce power alongside the gas turbines. (Academia, n,d).

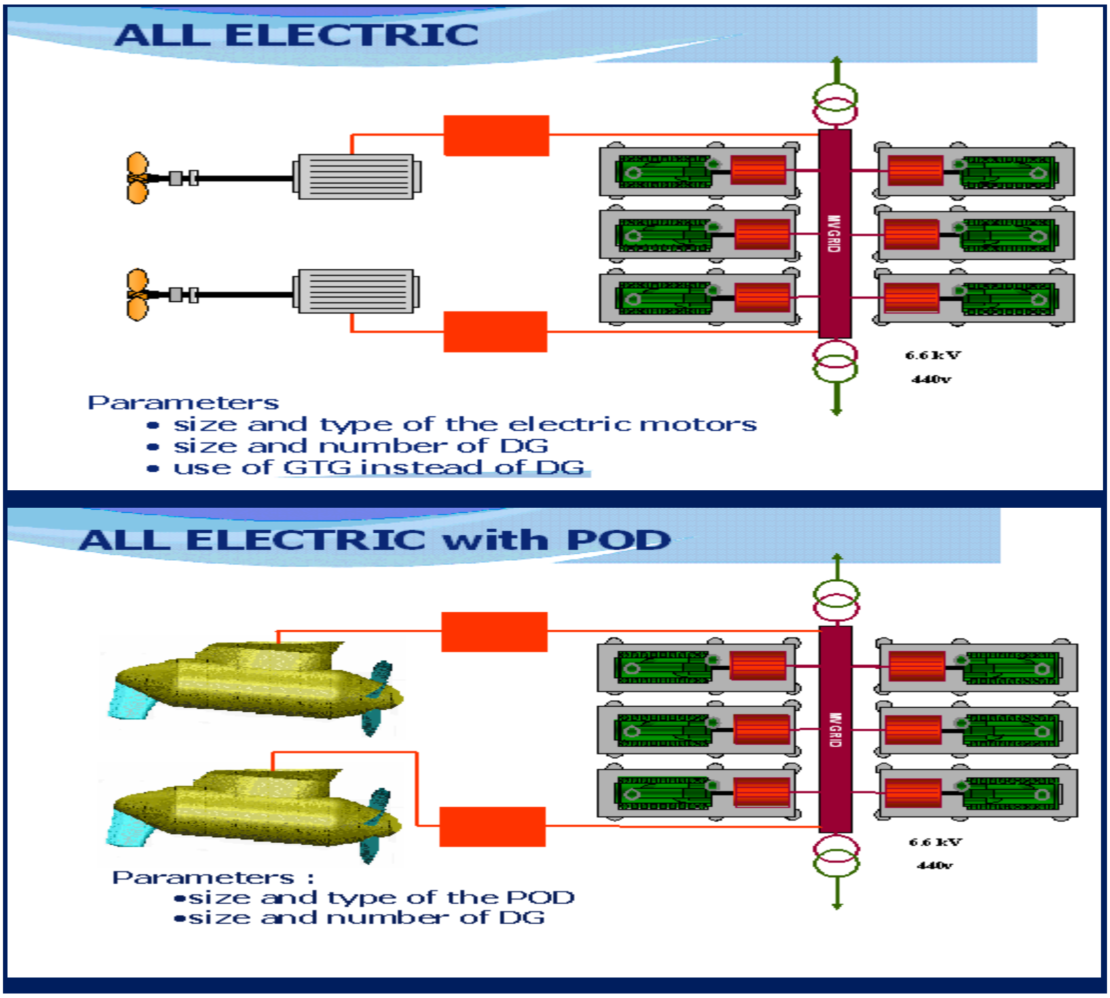


Picture 18. Comparison between traditional naval propulsion and electric drive with integrated electric drive. (Directorate of Marine Engineering)

The IFEP propulsion system is much more advanced and automated compared to IEP and FEP propulsion systems. The number of moving parts is minimized and the whole power output is available as electrical power.

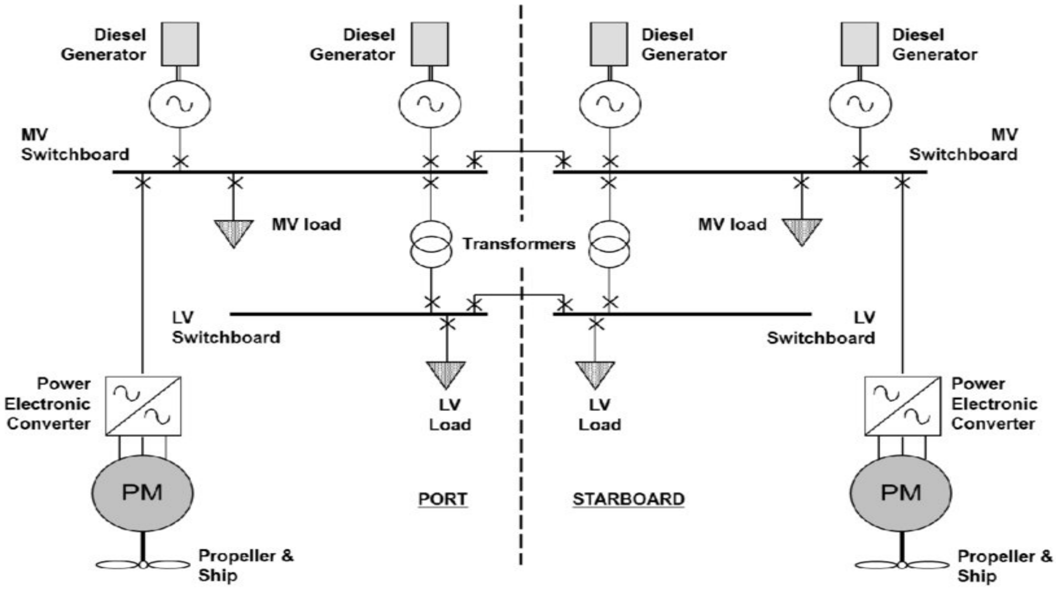
The benefits of the system include the following: noise and vibration is much lower than in vessels with more mechanical rotating parts, manoeuvrability and station keeping is improved with automation and PODs, fuel consumption is reduced, flexibility in designing spaces for equipment, environmental impact is reduced, power is available for non-propulsion use, number of crew can be decreased, life time costs of the ship is lower and flexibility for upgrades during the vessel's life time is better. (Apsley, 2009).

Higher acquisition costs, limited suitability for smaller ships and high voltage intricating power management can be mentioned as disadvantages of the system. The IFEP system is used in big ships like in amphibious assault ships, destroyers, aircraft carriers and in military cargo ships mostly because of their suitable size. (Apsley, 2009).



Picture 19. All electric propulsion arrangements in navy vessels. (Ficci, n,d)

IFEP configuration is suitable for medium speed diesel-engines. For example, French amphibious assault ship Mistral -class has three 16V32 (6.2 MW each) and one Wärtsilä 18V200 (3 MW). The power distribution configuration is flexible, so it is possible/desirable to have engines with different power output in the system, aiming at an optimal usage of the engines. (Ficci, n,d).

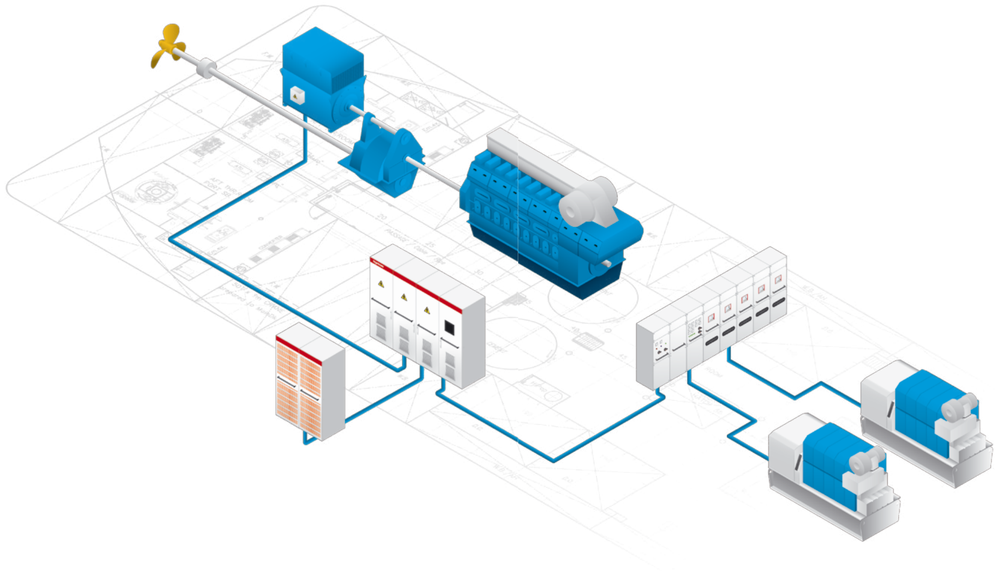


Picture 20. Typical IFEP architecture lay-out. (Schuddebeurs, 2014)

The architecture lay-out is also much more sophisticated in IFEP configuration than in IEP and FEP. The complexity is due to power management and automation that is essential, however, the system enables optimum power distribution between propulsion and other consumers. (Schuddebeurs, 2014).

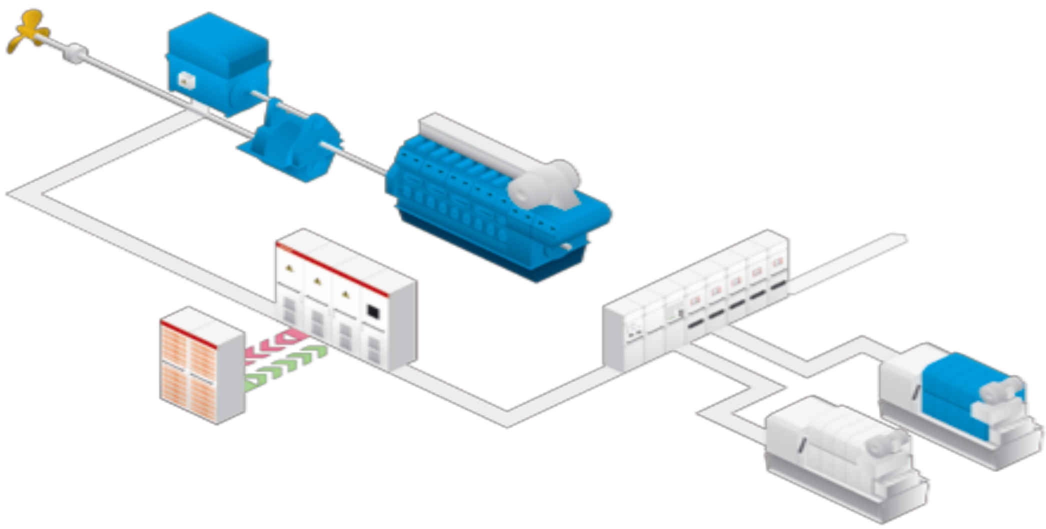
4.6 Hybrid propulsion options

Hybrid propulsion compatibility to naval use has been explored during the last decade and it has woken interest among naval engineering companies and states that have an intention to build new naval vessels. Hybrid propulsion has following advantages in naval use: fast and flexible response in variable power demand situations, propulsion system is highly reliable and redundant, power grid voltage is fixed, stable and no need for reduction gear, engines can be operated at optimal load range which reduces fuel consumption and emissions, lower maintenance costs due to the less rotating mechanical parts, less noise underwater and possibility to use boost in full power/speed mode. (Ingeteam, n.d).



Picture 21. PTI/PTO Hybrid electrical drive. (Ingeteam, n.d)

In hybrid electrical Power Take In (PTI)/Power Take Out (PTO) system, electrical and mechanical propulsion is combined into a kinematic drivetrain. Different operating modes have a great influence on optimizing engine load. (Ingeteam, n.d).

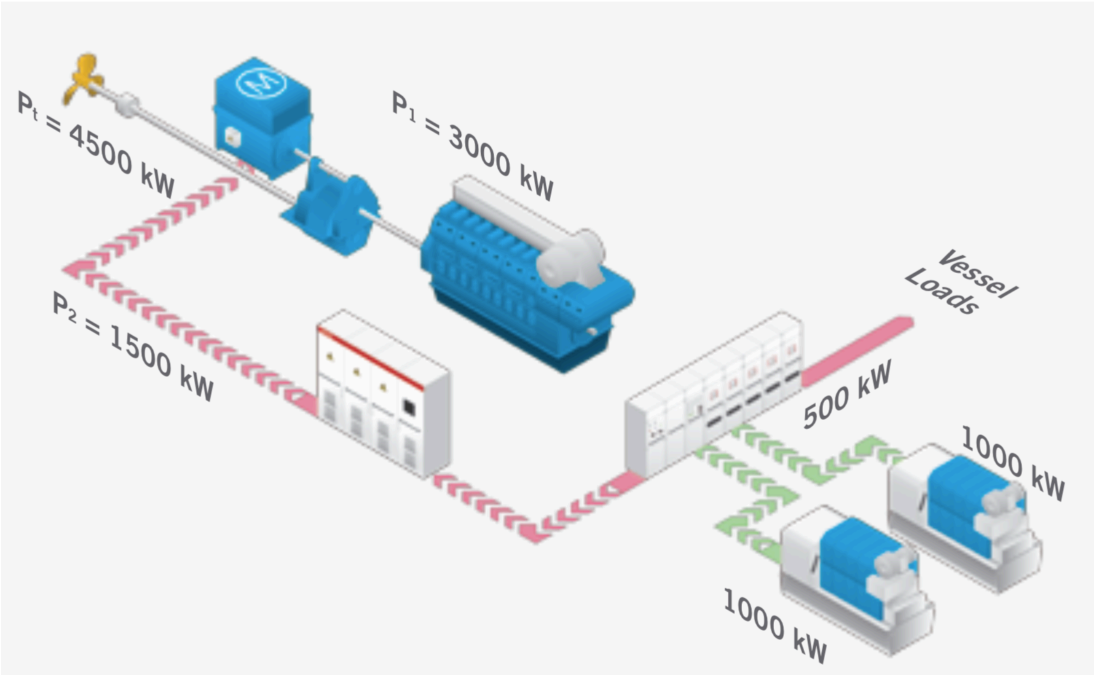


Picture 22. Hybrid energy storage. (Ingeteam, n.d)

Battery Energy Storage System (BESS) is useful as an aid to help the engine/generator sets to run in optimal load with minimum SFOC. When more power must be delivered to the shaft, BESS system is used to boost the power and keep the engine load optimal. And vice versa: when less power is delivered to the shaft power output, BESS delivers less or no power and is charged. The power and duration depend on battery type. (Ingeteam, n.d).

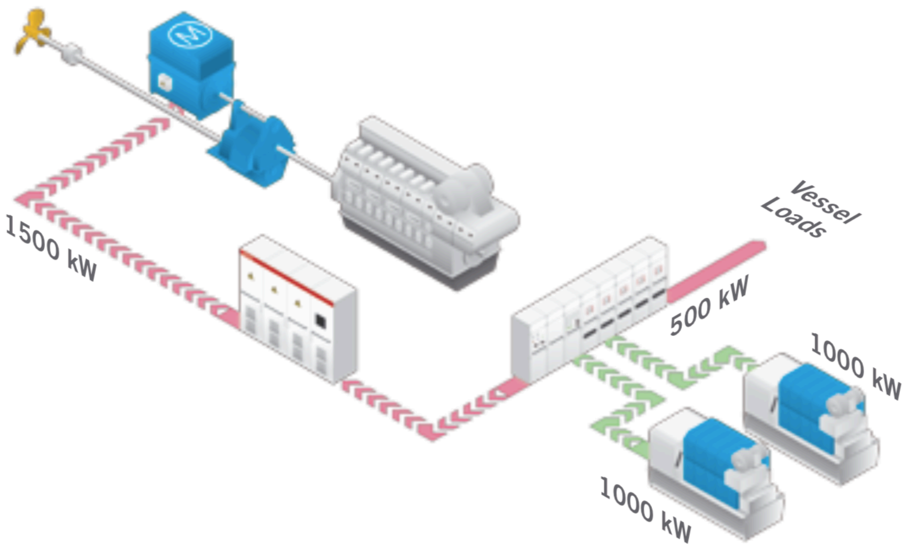
4.6.1 Hybrid electrical drive -operating modes

As mentioned earlier, awareness of different driving modes is important for optimum use of the hybrid system. The different modes are described below. (Ingeteam, n.d).



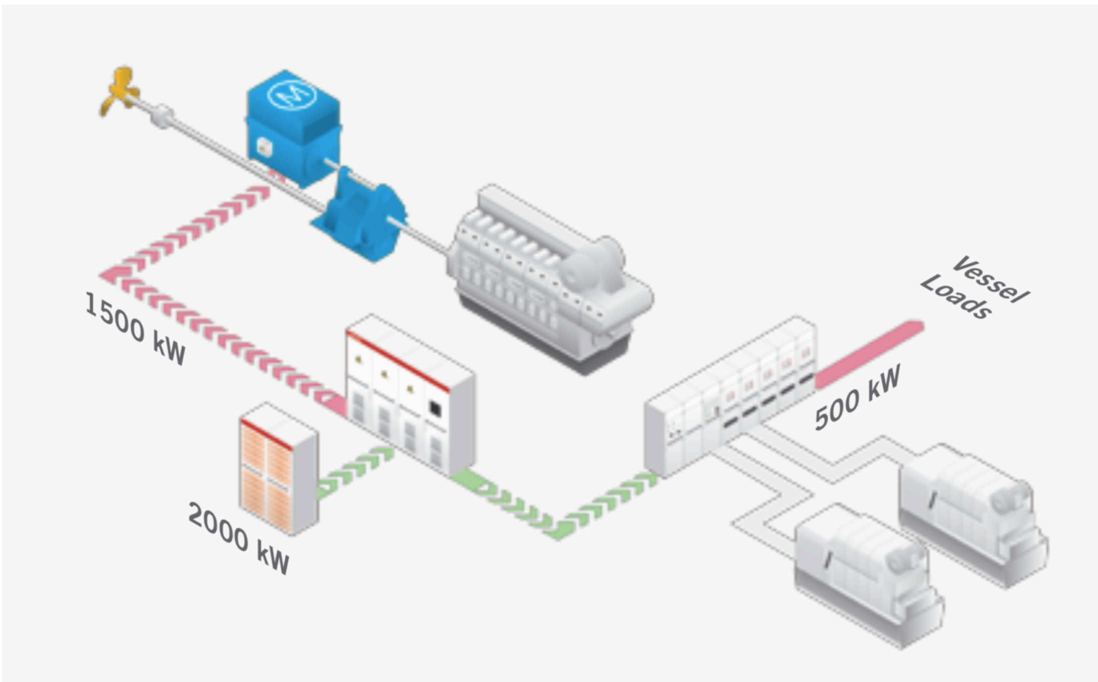
Picture 23. Hybrid electrical PTI booster mode. (Ingeteam, n.d)

In PTI booster mode the gensets produce electrical power to other vessel loads and to the shaft generator which is acting as a motor and is connected to the same gear with the main engine. The total shaft output consists of the main engine output plus the power of gensets, from which other vessel loads is deducted. (Ingeteam, n.d).



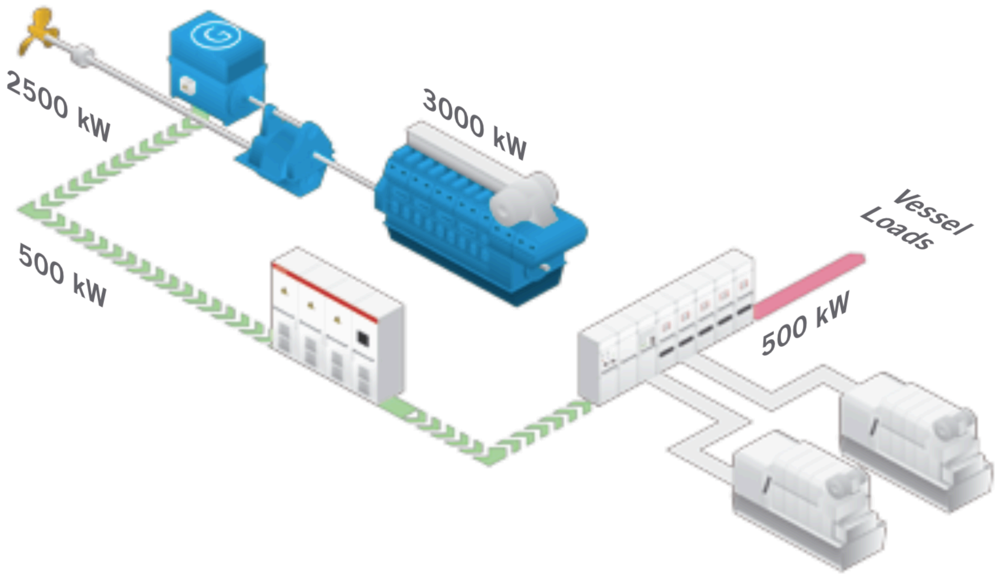
Picture 24. Hybrid electric PTI diesel electric mode. (Ingeteam, n.d)

At low speed or in case of main engine failure, gensets can be operated as main power source allowing safe return to port. This mode reduces significantly underwater noise. (Ingeteam, n.d).



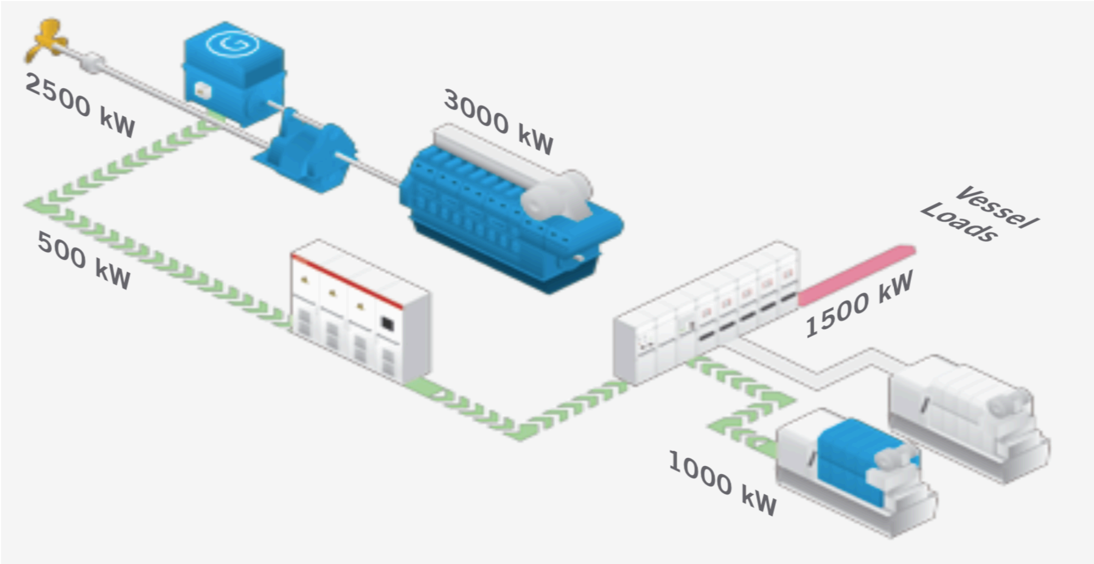
Picture 25. Hybrid electric PTI fully electric mode. (Ingeteam, n.d)

In PTI fully electric mode, a battery system is added to the propulsion system to supply power both to hotel loads and propulsion via shaft generator, which acts in this situation as a motor. No diesel engines are used so noise and gas emissions are eliminated. (Ingeteam, n.d).



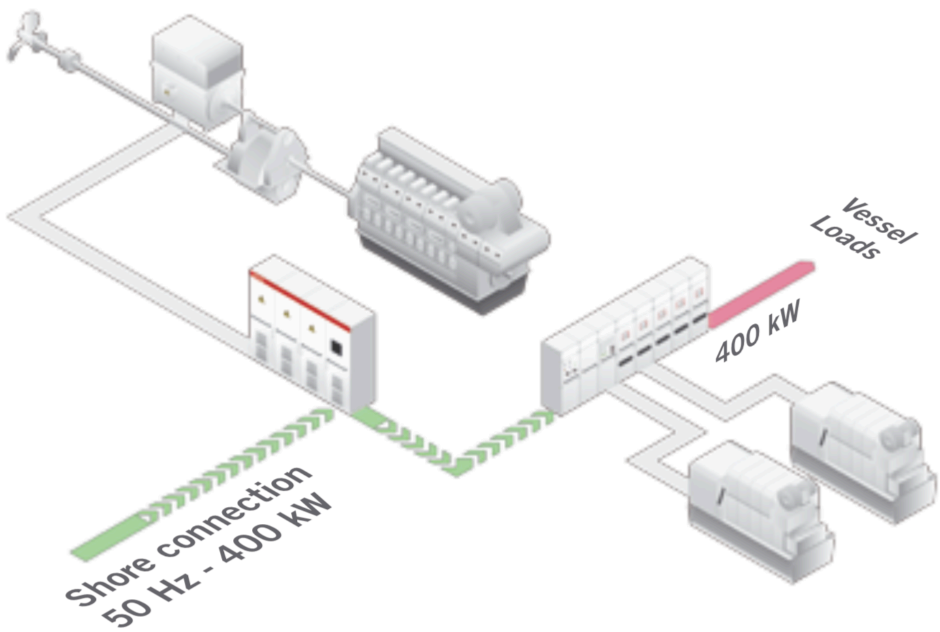
Picture 26. Hybrid electric PTO hybrid mode. (Ingeteam, n.d)

The shaft generator can be used in PTO mode when it is driven by the main engine. The main engine produces electricity to vessel hotel loads. Significant fuel savings and emission reductions is achieved by operating the main engine with optimal load. (Ingeteam, n.d).



Picture 27. Hybrid electric PTO parallel mode. (Ingeteam, n.d)

In hybrid electric PTO mode, the shaft generator driven by the variable speed main engine can be used parallel with diesel genset. If the vessel electricity loads are high, the main engine PTO can be used as a generator parallel with diesel generator to fulfill the vessel's electricity demand. (Ingeteam, n.d).



Picture 28. Hybrid electric PTO shore connection mode. (Ingeteam, n.d)

In shore connection mode all diesel engines are shut off and the electric power comes from shore. The machinery is ready for quick start-up if needed. (Ingeteam, n.d).

4.6.2 Suitable Battery Storage Systems

Battery storage systems give a lot of flexibility in vessel use. The stored energy can be used as additional power for propulsion, in some cases to black-out prevention and what is essential to Navy vessels, for quiet operation at low speed. Batteries are developing all the time and currently up to 18 MW battery systems are available. In the table below, three most common battery types are compared by energy density (Wh/kg), cycle life, power (W/kg) and costs per kWh. Since there are several sub-types of these three battery types, the extreme values for each type are indicated. (Hoedemaker 2017).

Table 5. Battery type comparison. (Hoedemaker 2017).

Battery type	**Lead-Acid**	**Nickel-Based**	**Lithium-ion**
Energy (Wh/kg)	30 - 50	45 - 120	100 - 250
Cycle life	200 – 300 cycles	300 - 1100 cycles	300 – 7000 cycles
Power (W/kg)	50 – 180	150 - 1000	250 - 3000
Costs (€/kWh)	100 – 200	300 – 600	250 - 1500

The use of batteries in Navy ships would probably be limited to non-combatant ships like combat support ships, coast/border guard vessels and to other support ships because the possible magnetization, extra weight and space requirements caused by the battery units would be harmful to combatant ships like destroyers, frigates and corvettes.

Non-combatant ships, unlike combatant ships can use battery systems as propulsion power boost, as a source of energy for the hotel load when the ships is anchored or moored and to quiet/low speed operations. Even though the lithium-ion type of battery system is the most expensive, it seems to be the best and the most long-lasting type to abovementioned vessel types. Like all battery types, the lithium-ion battery has advantages and disadvantages. (Hoedemaker 2017).

Advantages:

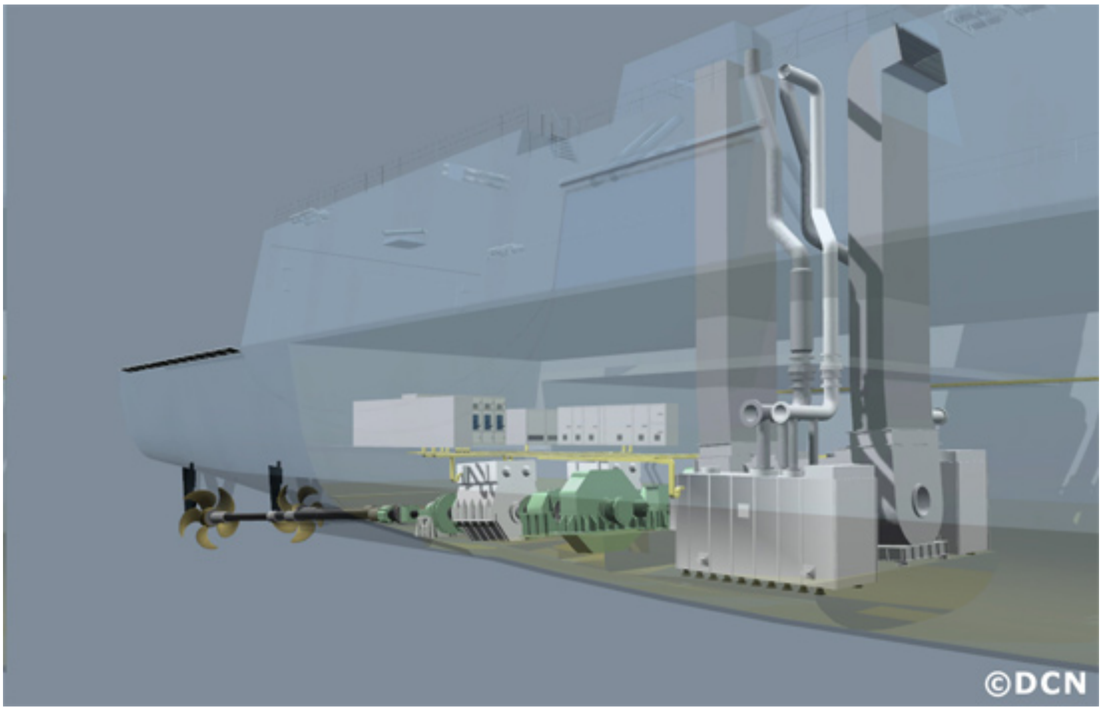
- High capacity and energy because lithium-ion has low internal resistance
- High power application suitability
- Size and weight, lithium-ion batteries are much smaller in size and only one third of lead-acid battery's weight with equal specific energy
- Fast charging time due to lower internal resistance
- Low self-discharge
- Low memory effect, Lithium-ion doesn't lose much maximum energy capacity when repeatedly charged
- Lithium-ion requires very little maintenance, cell balancing is the main maintenance which is incorporated into battery management system
- Constant power due to flat discharge curve
- High cycle life
- Low toxicity

Disadvantages:

- Higher acquisition price due to higher manufacturing price and more complicated monitoring and protecting circuit
- Uncontrolled thermal runaway
- Aging
- Narrow temperature area, must be operated in a right temperature, otherwise thermal runaway increases and battery life cycle decreases
- Strict transport regulations because Lithium-ion batteries are dangerous goods

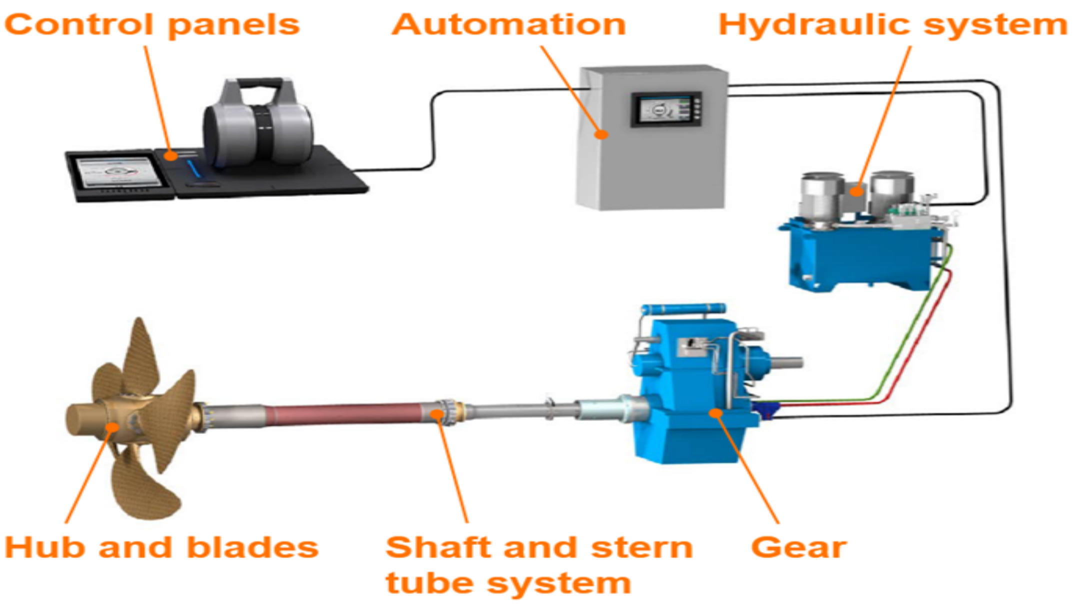
4.7 Propeller arrangement options

The propeller type in different vessel types is entrenched. This is due to the speed required for the ship. Usually the required speed is achieved with two 5-bladed controllable pitch propellers in high-speed destroyers and frigates. Other vessels including Amphibious, Helicopter carriers, Assault, Combat Support Ships and Coast/Border Guard vessels are much more configurable depending on ship's mission. The bigger width and particularly in Amphibious ships, Helicopter carriers, Assault ships and Combat Support ships, the bigger length combined with lower speed requirement enables the use of different kinds of propeller and podded thruster solutions. (Zarbock, 2009).



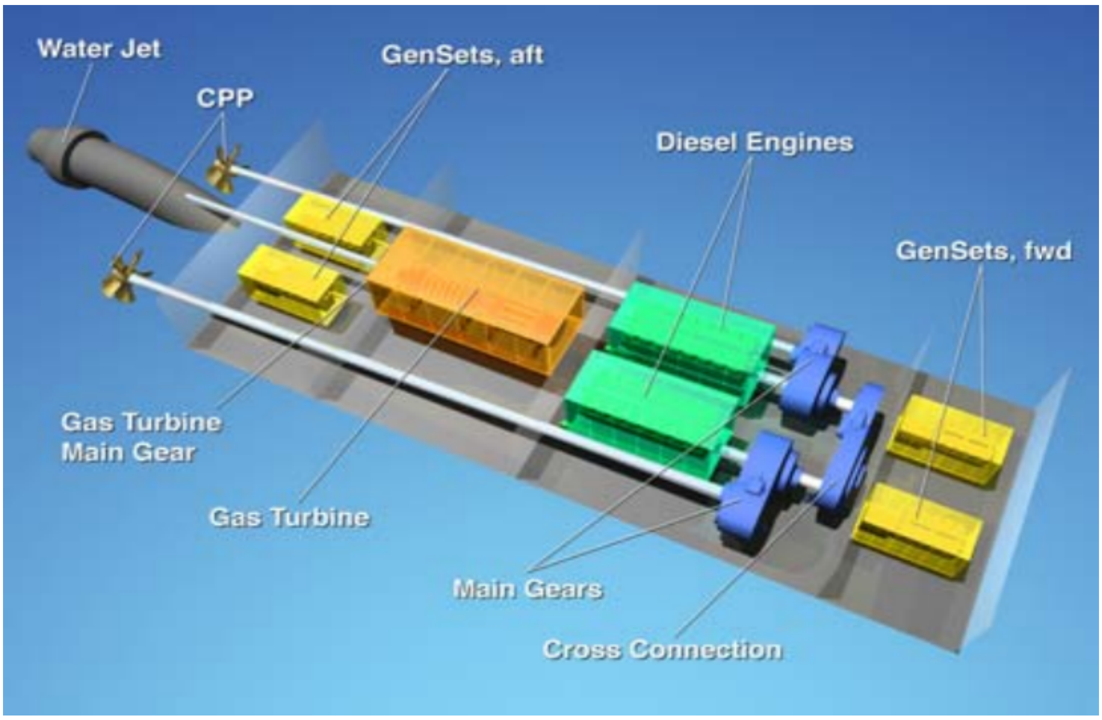
Picture 29. Fremm -series frigate propeller installation. (Naval Technology, n.d)

A very typical propeller installation for destroyers and frigates is presented in picture 29. It consists of two shafts and two 5-blade CPPs. The main reason for the use of a 5-blade propeller instead of a 4-blade CPP is that the power spreads over a bigger area and therefore the 5-bladed propeller reduces vibrations in ship's hull and the underwater noise level. CPP propeller has also high efficiency, it reduces fuel consumption and it enables easier manoeuvrability of the ship. (Marine insight, 2019).



Picture 30. Wärtsilä WCP Controllable Pitch Propeller. (Wärtsilä CPP, 2018)

The main structure of CPPs has been the same for a long period of time, excluding minor changes in lubrication and in energy efficiency which has been implemented by improving the performance of propeller blades. Naval CPPs are available up to 50 MW power and the blades are an area of technology which is under constant development. (Wärtsilä, 2016).



Picture 31. MEKO A-200SAN -type CODAG-WARP propeller arrangement lay-out. (ForcesDz, n.d)

A propeller modification for frigates and to other smaller ships is the CODAG-WARP, where a water jet nozzle is added in between, above and higher from the propellers in aim to reduce disturbance that water flow from the nozzle causes to the traditional propellers. The water jet -system is driven by gas turbine. It is really light system but the biggest problem with CODAG-WARP is that it cannot operate in ice covered areas.

Picture 32. Finnish border guard vessel Turva hybrid propeller arrangement with two CPP azipulls and one conventional shaft with CPP propeller. (Saarinen, 2013)

Other navy vessel types (amphibious ships, helicopter carriers, assault ships, combat support ships and coast/border guard vessels) have a wide variety of different propeller solutions. Depending on the mission and the purpose of these vessels, conventional two propeller system, azimuth/s or combinations of these is normally the propeller solution. In picture 32 is shown the Finnish border guard vessel Turva propeller arrangement. The machinery and propeller solutions enable four different operating profiles which are shown in the table below.

Table 6. CGV Turva operating modes and specification. (Saarinen, 2018).

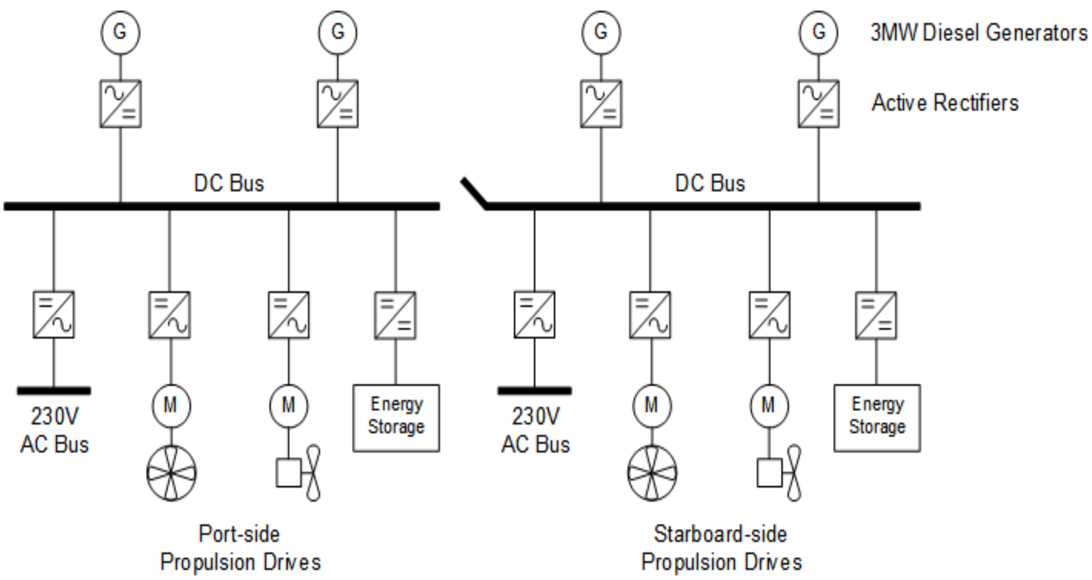
	Mode one	Mode two	Mode three	Mode four
Engines	Wärtsilä 2 x 6L34DF	Wärtsilä 12V34DF + 1 x 6L34DF	Wärtsilä 12V34DF + 2 x 6L34DF + 6L20DF	Wärtsilä 12V34DF
Power source for the hotel load	Wärtsilä 2 x 6L34DF	Shaft generator	Wärtsilä 6L20DF	Shaft generator
Power output (kW)	5400	8100	11676	5400
Speed (knots))	14,5	15	18+	13
Consumption on Diesel use (Litres/h)	1000	1300	2000	850

4.8 DC vs AC power grid in propulsion use

Present diesel-electric naval vessels are AC -based systems. Navies planning a new-building warship are exploring the possibility to use DC based system in propulsion use and the transition is going to happen possibly via hybrid solutions where both AC and DC main bus is contained simultaneously. (Prenc, Cuculic, Baumgartner, 2016).

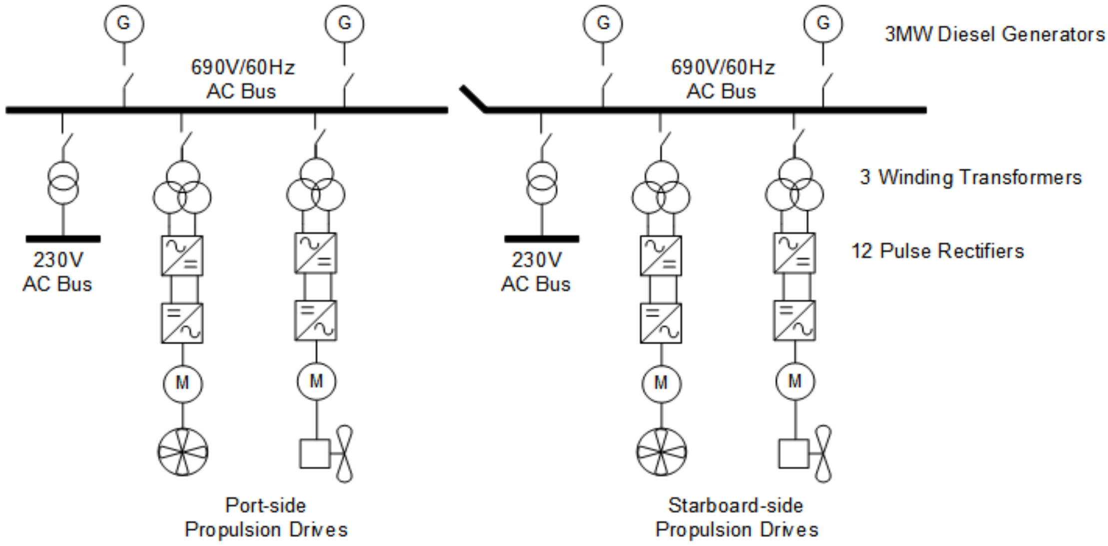
Shifting from AC based propulsion systems to DC propulsion systems in naval use has challenges such as high short-circuit currents, expensive energy storage systems and DC protection coordination which protects the system in case of a fault. But there are also benefits like reduced space requirement, smaller weight, unity power factor when operating generators, reduced transmission losses, fast and simple parallel connection of generators with no need of synchronization, fuel costs reduction, prime mover efficiency improvement and simple implementation of energy storage. (Prenc, Cuculic, Baumgartner, 2016).

The DC based propulsion system itself is not a new invention. DC systems have been used for a long time in submarines but there are no references of surface naval vessels whose functionality could be assessed. DC alternators/generators exist but due to the carbon brush construction, the aptitude to convert large amount of power is limited and the efficiency is lower than in AC alternators/generators. By implementing the DC system as shown below with active rectifiers, the efficiency gain can be improved. The above-mentioned issues have greatly contributed in selection of the most feasible solution. (Prenc, Cuculic, Baumgartner, 2016).



Picture 33. Low voltage DC propulsion system. (ScienceDirect, 2017)

The biggest difference between a low voltage DC (LVCD) and a low voltage AC (LVAC) is the change to 1kV DC bus from 690V AC bus. Active front end converters (AFE) are required to convert AC voltages to DC as the generators remain the same and no three-winding transformers, circuit breakers and 12 -pulse rectifiers are needed. Electricity power to propulsion motor can be sourced direct from 1kV DC bus, however, DC to DC converters for energy storage are required for power flow control between DC bus and the energy storage system. Step-down transformers to 230V and to 400V are replaced with DC to AC inverters. (Prenc, Cuculic, Baumgartner, 2016).



Picture 34. Low voltage AC system. (ScienceDirect, 2017)

Since DC based propulsion systems have been in use for a long time in submarines, shock and redundancy requirements shouldn't be an issue. There are no standards for DC propulsion use in navy vessels at the moment but a draft of the standard that is going to be under MIL-STD 1399 for low voltage DC and high voltage DC has been presented. (Everyspec, 2018).

Table 7. DC propulsion grid standards which are used in commercial vessels and which probably are going to be used in navy vessels also in future. (Tandfonline, 2018).

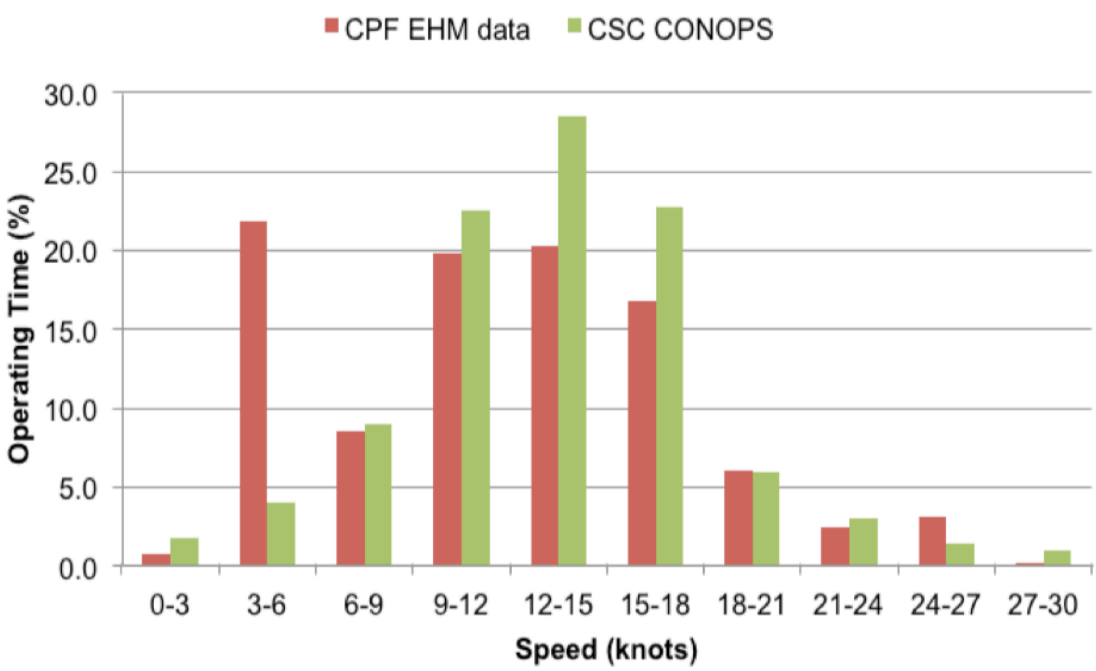
Organi-zation	**No.**	**Title**	**Publication year (edition)**	**Remarks**
IEEE	1709	IEEE Recommended Practice for 1–35 kV Medium-Voltage DC Power Systems on Ships	2010 (ed. 1)	General guide-line (>1 and ≤35 kV_{dc})
ISO	16315	Small craft – Electric propulsion system (some parts for the DC distribu-tion)	2016 (ed. 1)	For small ships (<1 kV_{dc} and <24 m in length)
IEC	63108 (PAS)	Electrical installation in ships – Primary DC distribution – System design architecture	2017 (ed. 1)	General stand-ard

	61660-1	Short-circuit currents in DC auxiliary installations in power plants and substations – Part 1: Calculation of short-circuit currents	1997 (ed. 1)	Short-circuit calculation in DC-grid
	60092-507	Electrical installations in ships – Part 507: Small vessels (some parts for the DC distribution)	2014 (ed. 3)	For small vessels (<50 m in length, and ≤500 GT[1])
	60092-201	Electrical installations in ships – Part 201: System design – General	1994 (ed. 4)	In chapter 4 (DC distribution systems)
	61892-1	Mobile and fixed offshore units – Electrical installations – Part 1: General requirements and conditions	2015 (ed. 3)	For offshore units in chapter 4.6, annex D (≤1.5 kV_{dc})
NAVSEA	STD-1399(navy) LVDC section	Electric Power – Low Voltage and 1000 V Direct Current	2016 (draft)	US DoD[2] standard (≤1 kV_{dc})
	STD-1399(navy) MVDC section	Electric Power – High Voltage Direct Current	2016 (draft)	US DoD standard (>1 kV_{dc})
IACS	UR[3] E5	Voltage and frequency variations	2005 (rev. 1)	Voltage variations for DC-grid
NFPA[4]	70E	Standard for Electrical Safety in the Workplace – Annex D	2018	DC arc flash calculation

5 CONCEIVABLE FUTURE NAVY AND COAST/BORDER GUARD VESSEL MACHINERY LAY-OUT

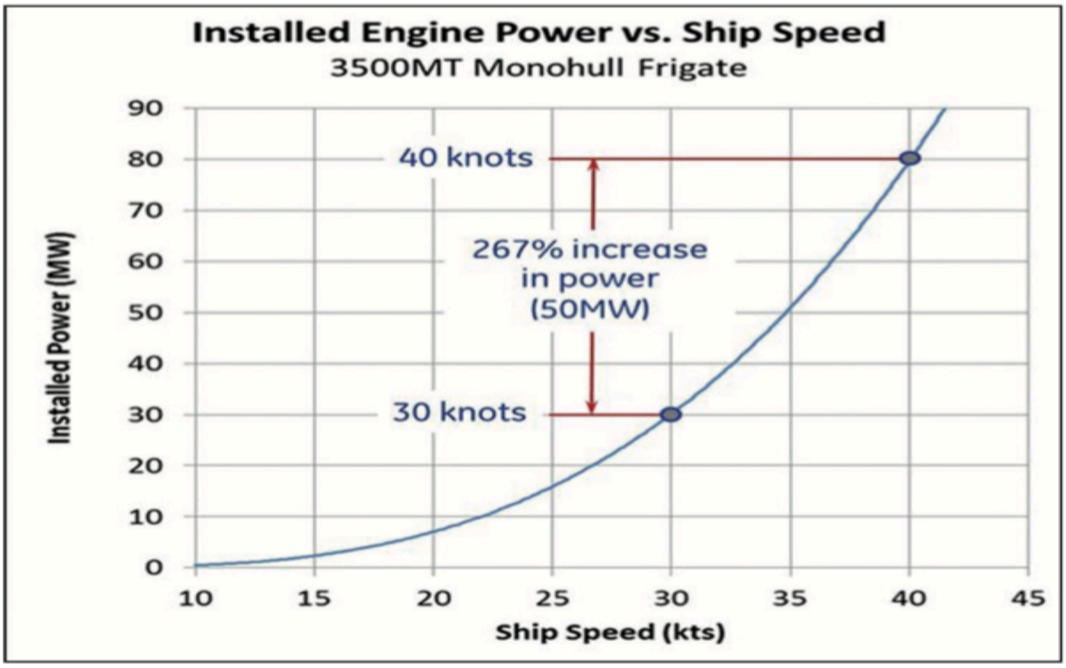
5.1 Power/speed curve vs operating profile

The power requirement increases considerably in frigate and destroyer -class navy vessels if speed is specified to be over 25 kt. Traditionally these vessel classes have had speed requirement over 25 kt and gas turbines has generally been used as power source to achieve the specified high speed. Other critical factors for power output is the width of the vessel and modern weapon systems that have a higher power demand than the former ones. Since the power demand of different type of weapon systems is not public information, it can only be assumed that the power demand lies somewhere between 1-2 MW. Destroyers are often longer than frigates and the length offer more different machinery installation options. In frigates the width of the vessel is often the problem. Increasing the beam automatically increases the power requirement because a broader vessel requires much more power to reach the same speed as a narrow vessel with the same weight. (Work, 2016).



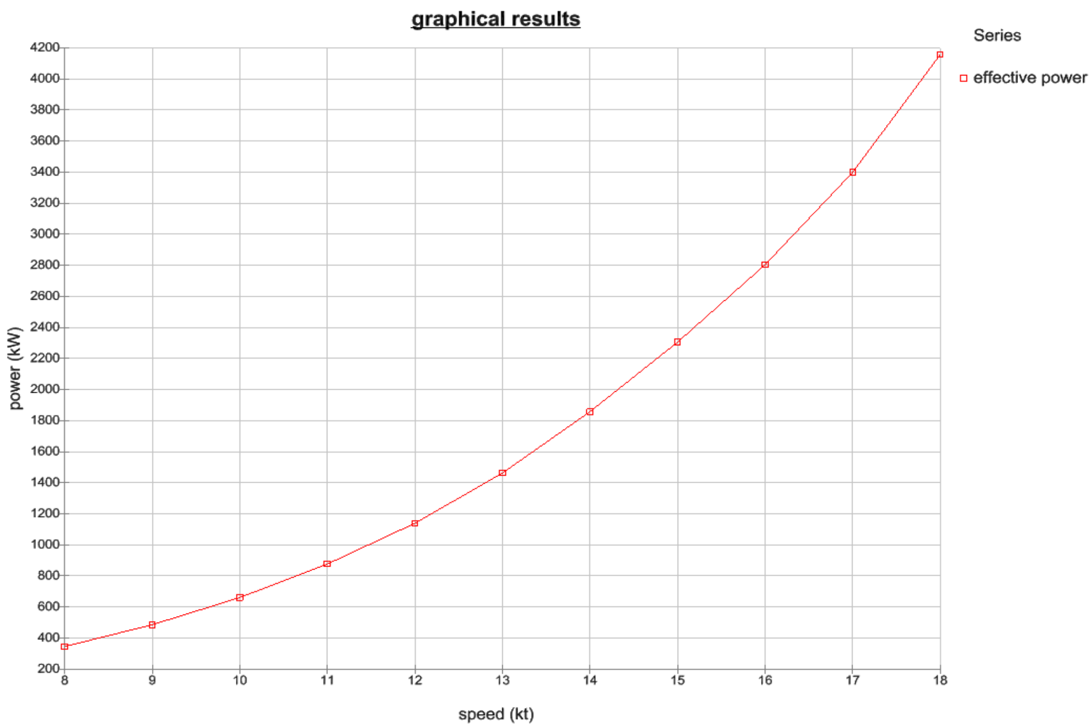
Picture 36. Canadian Frigate operating profile comparison table. (Work, 2016)

Operating profile comparison between present Canadian Patrol Frigate (CPF) and its replacing Canadian Surface Combatant (CSC) in picture 36 shows that the operating time between 9-18 kt is expected to increase. Operating data for CPF is taken from Equipment Health Monitoring System (EHM) and CSC operating profile is assumed in CONOPS according to ANEP77. (Work, 2016).



Picture 37. Power-speed curve for Monohulled Frigate. (Maynard, 2015)

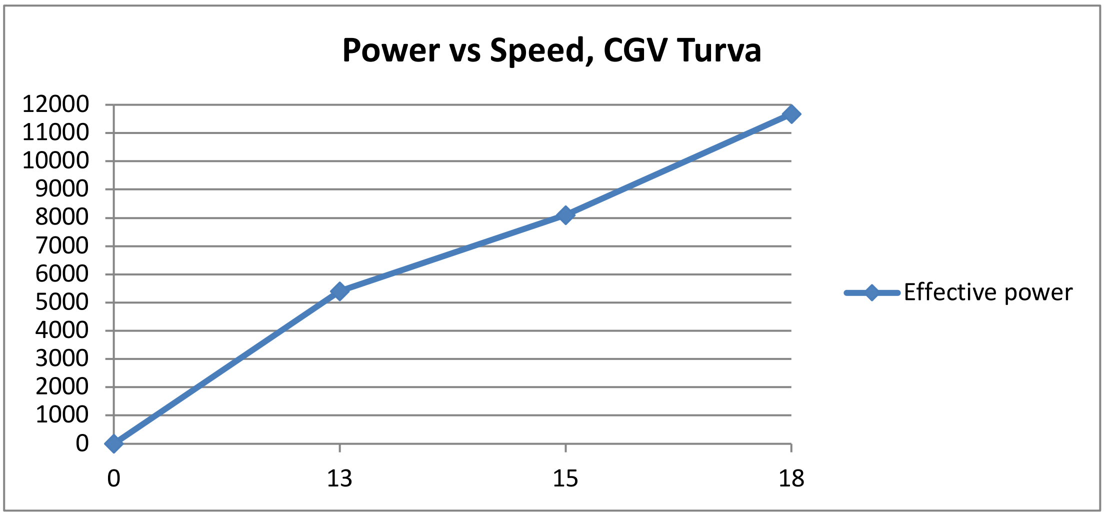
Increasing the speed of monohulled frigate increases the power need also considerably as shown in picture 37. If speed requirements are specified below 27 kt, machinery installation is possible to implement with medium speed diesel engines. The increase in speed from the aforementioned 27 kt increases both the construction and operations costs. (Maynard, 2015).



Picture 38. Power vs speed curve for Canadian Offshore Patrol Vessel with displacement of 1417 tonnes, length 62,50, beam 11m and depth of 3.5 m. (Name 591, n.d)

Predicted power vs speed curve for Canadian Offshore Patrol vessel calculated with Holtrop method is shown in picture 38. The Holtrop method is a formula of calculation that is used to predict power demand for vessel that which is in the design phase. (Research gate, 2018).

Table 8. Power vs speed curve for Finnish Border Guard vessel Turva. (Saarinen, 2018).



Power vs speed curve for Finnish Border Guard vessel Turva is presented in Table 9. The vessel Turva has displacement of 4000 t, length 95,9 m, beam 17,4 m and depth 5.5 m. Compared to the 1417 t Canadian OPV, power demand for Turva to achieve same 18 kt speed is considerably higher. Hull form defines power demand as the difference between these two vessels are that the Canadian OPV achieves the 18 kt speed with approximately 4200 kw and Turva achieves the same speed with 11600 kw. (Saarinen, 2018).

If a cost-effective warfare ship is desired, the biggest question is about the actual need to achieve 30 kt instead of 25 kt, since both building and operational costs are increased considerably because of the specified extra speed.

5.2 Combatant Destroyers/Frigates

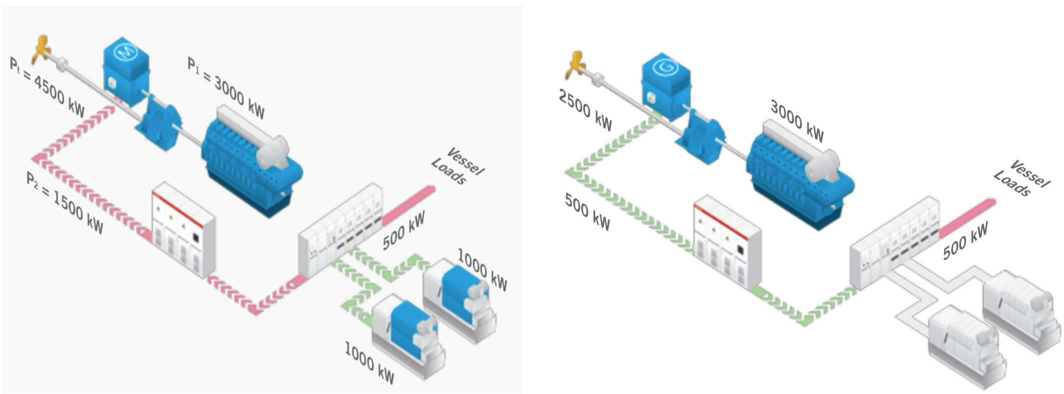
As aforementioned, it depends on countries whether they call some ship class as Destroyers or Frigates, both vessel classes are surface combatant vessels in same size and have a similar mission.

Countries that have an intention to build new surface combatant ships have clearly a desire to replace gas turbines with an alternative technology. The hull and the propeller arrangement are proven and it has not become apparent in this study that something new would be coming to those parts of the newbuilding Navy combatant ships. If the intention is to reduce life-time operational and maintenance costs, the most suitable and feasible way would be to run two 8 MW to 10 MW medium speed diesel with cross connect gearbox, PTI/PTO generator and two to three 1,5 MW medium speed diesel gensets for hotel/fighting load and for silent mode operation. When comparing the aforementioned machinery lay-out to traditional lay-out with high speed diesel engines and gas turbine, it has numerous benefits and but also a few disadvantages:

Benefits:

- Life-cycle fuel costs savings

- Lower maintenance and spare part costs
- Numerous operating modes for optimal engine load
- Redundancy
- Medium speed diesel engines are in general less sensitive for failures due to lower RPM: s and more robust structure
- Wider range in specified fuel quality (STANAG 1385)
- Less SFOC (Specified Fuel Oil Consumption) means wider operation range and time between need to bunker the vessel
- Depending on 8 MW to 10 MW engine type, modularity if needed



Picture 40. Possible medium speed diesel lay-out with PTI/PTO. (ingeteam, n.d)

Disadvantages:

- Configuration is heavier than implemented with high speed diesel engine and gas turbine/s → what is the impact on speed and weight distribution
- Bigger space requirements → should not be so much more that it couldn’t be put into practice
- No existing reference ships

When the thesis has progressed, it has become clear that the weight and space requirements are critical in surface combatant ships but from my point of view the problem occurs when a top speed over 25 kt is required. According to power/speed curve for monohulled Frigate in Picture 37, it is possible to achieve top speed of 27 kt with 21 MW power output medium speed diesel engines, assuming that the table in Picture 37 is calculated for high-speed diesel configuration with less weight. The extra weight in medium speed diesel -configuration may cause some reduction in speed but the most critical factor is that the width of the assumed vessel does not have to be increased.

Picture 41. British Light Frigate Concept (VLF), the Venator. (BMT Defence Services, n.d)

5.3 Non-combatant ships

Non-combatant ships include many kinds of ships like Offshore patrol vessels (OPV), Amphibious warfare ships, Amphibious transport ships, Assault ships and combat support ships with displacement between 1000 t and 27500 t. Difference between combatant and non-combatant ships is that speed demand is normally 22 kt or less but manoeuvring demand is higher. Therefore, these vessels are usually equipped with diesel-electric pods and dynamic positioning system. (Saunders, 2018).

Due to the lower speed demand and wider engine room spaces, medium speed diesel engines and new technology such as batteries, PTO/PTI lay-out and perhaps permanent magnet solutions are suitable for non-combatant ships.

The biggest part of non-combatant vessels in European navy and coast/border guards is OPVs'. The need of renewal this fleet is significant in near future due to their high average age which is approximately 18 years according to the publication Jane's Fighting Ships. OPVs' are the fastest growing segment on naval Vessels markets according to Offshore Patrol Vessels global market report 2018-2019. (Defence IQ, 2019).

There are significant differences in the ship’s structures due to the area where Offshore patrol vessels is used. Vessels operating at ice covered areas need to be able to operate in heavy ice conditions and are more robust built while vessels operating in open waters can be built without ice reinforcement.

5.3.1 Arctic Offshore Patrol vessels

The design is defined by the purpose of the vessel. Countries have different tasks for OPVs’. Finland, for example, has own regulations defining that besides the normal patrolling, the vessel has to be able to tow other vessels, to conduct search and rescue (SAR) missions, oil recovery and to have an overall ability to operate in any Baltic Sea weather conditions. Some countries use their vessels only for surveillance and to enforce sovereignty. (Rajavartiolaitos, 2014).

Picture 42. Project 03182, Russian supply/Arctic Offshore Patrol Vessel. (Navy Recognition, 2015)

The Russian Arctic Offshore Patrol Vessel in figure 45 is designed for multipurpose tasks. The width of the vessel (15.4 m) in relation to length (75 m) allows several kinds of machinery lay-outs. The planned operating area for the vessel can cause restrictions to LNG use because there must be an LNG terminal nearby for gas replenishment.
A CODELAD PTI/PTO hybrid electrical drive with battery pack shown in Picture 21, added with two azipull propellers like in Figure 32 combined with engines fulfilling TIER III emission requirements would provide necessary power in heavy ice conditions and would ensure low emissions.

Picture 43. Canadian Arctic Offshore Patrol Vessel (AOPV) Harry DeWolf -class. (Royal Canadian Navy, 2015)

The Canadian Arctic Offshore Patrol Vessel (AOPV) Harry DeWolf -class introduced in Picture 43 is another type of in ice going offshore patrol vessel. The length of 103 meters, width of 19 meters and ice breaking capability of 1-meter solid ice is achieved by 23,4 MW diesel electric propulsion. (Royal Canadian Navy, 2015).

The ability to operate in heavy ice-conditions is achieved with double acting hull form which basically means that the vessel operates normally forward but in heavy ice conditions the vessel turned around and operated to astern direction. (Royal Canadian Navy, 2015).

The dimensions of this type of AOPV give opportunities to use wide range of newest propulsion plant installations.

Picture 44. Hull form of the Canadian Harry DeWolf -class. (Thai Military and Asian Region, 2018)

5.3.2 Offshore Patrol Vessels for open sea areas

Open water Offshore Patrol Vessels are generally lighter and faster because they don't have to be ice reinforced. Hull form and straight shaft thrust increases the speed while the arrangement significantly reduces constructions costs. Operation profile varies from piracy prevention to environmental protection and the armament is usually heavier than in Offshore Patrol Vessels operating in ice covered areas.

The size of these vessels often lies between 70 meters and 110 m and the beam between 10 meters and 20 meters, mostly depending on the sea area where the vessel is planned to operate. The decisive factors for the usage of new technologies and machinery layout is speed demand and operation range. OPV:s usually have speed demand below 25 knots with cruising speed between 12-15 knots. Wider range can be achieved with medium speed four stroke diesel engines because their lower specific fuel consumption.


Picture 45. Open water offshore patrol vessel Vigilante 1400 CL79. (CMN, n.d)

In picture 45 is multipurpose Offshore Patrol Vessel Vigilante 1400 CL79. The vessel is very typical open water long range OPV with minimum range of 8000 NM at 12 knots. These types of vessels are fully compatible for CODELAD hybrid PTO/PTI lay-out with medium speed diesel engines, cross connect gearbox and straight shaft thrust. (CMN, n.d).

Picture 46. VARD 7 100 Offshore Patrol Vessel. (Vard marine, 2019)

In picture 46 is a bigger open water Offshore Patrol vessel Vard 7 100. These vessels have a length of 92,7 meters, breadth 14 meters, engine power output 20000 kW and range with speed of 14 knots, 9500 NM. (Vard marine, 2019).

The VARD 7 100 actually represents the basic machinery lay-out in near future with CODELAD (combined diesel electric and diesel) for Offshore Patrol Vessels. In further development the hybrid PTI/PTO systems is likely to be more and more attractive in OPV new buildings. (Vard marine, 2019).

The above mentioned non-combatant OPV:s and AOPV:s should not be mixed with naval Offshore Patrol Vessels (NOPS) since the term NOPS include combatant vessels.

6 OTHER REQUIREMENTS TO BE CONSIDERED

6.1 Shock requirements

It is essential to have shock protection in naval ships' vital systems. According to Allied Naval Engineering Publication (ANEP77), three standards are used to ensure that required systems are shock proof: ASTM F2877, STANAG 4141 and MIL-SPEC-901D. Normally shock tests are performed by the manufacturer who gives certificate to prove that the device is tested. However, in some cases with smaller equipment naval Administration can calculate or perform own test to ensure that the device can withstand the shock wave that impacts the hull when detonation occurs nearby the ship. These tests are usually not based on any standard because they are small installations that are not vital to the ship (ANEP77, 2014).

However, it is noteworthy that the requirements by naval Administrations or classification societies can deviate, or they can decide how to apply standards since ANEP77 contains only guidelines. For example, DNV GL uses ANSI S2.14-1973 Appendix C, IEC 68-2-27:1987: Appendix B and C, ISO 8568-1989 (E) and STANAG 4549 standards in shock testing but other standards like MIL-SPEC-901D can be used also if those guidelines are more appropriate or better for the intended use.

6.1.1 ASTM F2877 -standard

ASTM F2877 is a test method used to ensure that Steel or Aluminum insulation meets the requirements in shock event. The requirements are defined in its entirety in International Maritime Organization (IMO) resolution A.754 (18) (ASTM, 2018).

6.1.2 STANAG 4141 -standard

STANAG 4141 -standard contains method and test procedures of equipment for Navy Surface Ships. Unfortunately, this standard is restricted by its owner -North Atlantic Treaty Organization (NATO) and it cannot be found as a public source in internet.

According to Sperry Marine's design requirements, STANAG 4141 shock levels are higher than in United States Navy MIL-SPEC-901D standard (Brazell, Bruce, Mayer, n.d).

6.1.3 MIL-SPEC-901D -standard

MIL-SPEC-901D is unlimited distribution shock test standard for United States Navy. It is widely used all around the world perhaps because it is a public document which deals extensively shock related matters. It specifies how equipment onboard should be protected against shock impact in war situation so that the vessel would stay in operative use as long as possible (EverySpec, n.d).

6.1.4 Other related Navy vessel shock test standards

The naval Administrations and classification societies decide independently which guidelines they want to use in their shock requirements. Here are some other standards that are often used besides the aforementioned (Sebert, 2019):

- *MIL STD 810, Environmental test methods and engineering Guidelines*
- *STANAG 4138, Vibration Resistant Equipment – Testing Requirements*
- *STANAG 4549, Testing of surface ship equipment on shock test machine*
- *AECTP 400 Vibration (Method 401)*
- *AECTP 400 Shock (Method 403)*

6.2 Degaussing combat ship

One of the biggest threats for surface ships is caused by sea mines that is triggered by the electro-magnetic field of the passing vessel. Already in the building process magnetism is developed to the vessel by the earth's magnetic field which is called ship's permanent magnetic field. Other relevant factors regarding the magnetic field are eddy current, galvanic currents, electric circuits and magnets onboard (Nain, 2013).

An eddy current is caused by the changing magnetic field when the vessel is seagoing and rolling. Galvanic currents are created when two dissimilar metals are immersed in sea water such as zinc anodes and brass propeller. Electric circuits cause magnetic fields and are often categorized in permanent magnets. The end result of these is a magnetic field that changes all the time and this change around the magnetic weapon causes it to set off (Nain, 2013).

Degaussing of the ship is done to decrease its magnetic field to make it look as if there was no vessel near the mine that senses the magnetic field differences. Degaussing can be done either by magnetic treatment (Deperming) or by shipboard degaussing equipment which is more effective of these two methods (Nain, 2013).

7 SUMMARY

7.1 Conclusions

On the basis on the material examined to this master thesis, it became obvious that naval Administrations have an interest to increase the use of gas turbine technology in possible surface combat vessel newbuilding's.

All installation types covered by this thesis have their own merits and drawbacks. Gas turbines are light weight but they have high specific fuel oil consumption. High-speed diesel engines are rather light weight but they also have quite high specific fuel oil consumption. Moreover, a big overhaul often means engine replacement. Four stroke medium speed diesel engines have lowest specific fuel oil consumption combined with longest overhaul interval but this type of installation is also considerably heavier.

The most critical factors of surface combat vessel are beam and displacement. If the beam or displacement is increased due to weight, the length of the vessel needs to be increased as well, to achieve the required speed. For example, if high-speed diesel/gas turbine CODOG or CODAG installation were to be converted to CODAD installation with medium speed diesel engines, it would be necessary to reduce the length and width of the vessel to achieve the same speed. A change in vessel dimensions due to increased weight would automatically lead to an increase in the power need/number of diesel engines, if the requirement is to maintain the same speed as with gas turbine installation.

Although computer modeling can be done, the final experience and evaluation about a combat Frigate equipped with a four-stroke medium speed diesel engine without gas turbine/s could be achieved only after some time of operational use. The biggest problem in building a Frigate with new type of machinery installation seems to be that no naval Administration want to be the first "guinea pig" and try it out. In that sense, development is stagnating and the basic idea of machine arrangements has remained almost the same since the second world war.

Non-combatant ships have opposite requirements, i.e. the range and the length of operation time are crucial. These requirements are reflected in machinery solutions as more traditional four-stroke medium speed diesel installations.

The implementation of rules and regulations used in Navy and Coast/Border Guard newbuilding vessels differ considerably from the implementation of merchant vessel rules and regulations. Vessels can be built according to some rules and regulations of a classification society or the vessel can be built into a class. If the vessel is built according to some rule or regulation, the naval Administration takes the needed information from classification societies' rules and regulations and applies them in the way that best suits to their purposes. However, the classification society has nothing to do with the actual newbuilding. Another possibility is to build the vessel into a class for some part or entirely. The chosen classification society then participates in surveillance of application of the rules and regulations during the of the ship. Because of aforementioned, used standards, practices, regulations and demands in newbuilding vessels varies a lot between countries and naval Administrations.

A significant increase in construction and operating costs is expected if the ship's speed is planned to be over 25 knots. According to combat vessels' operating profile studied in this thesis, there is a need to use a maximum speed more than 25 knots only 5% or less of operating time, so the actual need to build ships with top speed of over 25 knots can be questioned.

Newbuilding technology and machinery solutions both in combat and in non-combatant vessels will depend highly on the performance capability requirements that are set for the ship at the beginning of the design.

7.2 Recommendations

Although there are clear advantages of selecting a four-stroke medium diesel engine for frigates, destroyers and in other surface combatant vessels, its implementation seems unlikely in the near future because of the fact that four stroke medium speed diesel engines are twice as heavy as high-speed diesel engines. It is advisable to closely monitor engine solutions for these vessel types since naval Administrations show clearly an interest towards alternative technologies. However, lack of a reference ship seems to be an obstacle for decisions.

The auxiliary equipment of these vessel classes will definitely be in constant development. The development work at this stage supports the possibility of delivering a complete machinery solution to these vessel classes in the future, provided that the development goes towards four-stroke medium speed diesel installations without gas turbines.

The DC power grid development seems to have woken similar interest as four stroke medium speed diesel engine installation to newbuilding combatant vessels. However, the situation seems to be similar for both technologies and the development should be monitored closely.

Other non-combatant vessel types, combat support ships and especially offshore patrol vessel markets are perfect for Wärtsilä solutions. Besides Navies, Coast/Border Guards, Customs Services and Marine Police authorities use offshore patrol vessels in their operations because these vessels are more cost effective compared to war ships.

Wärtsilä already has a wide experience as an equipment supplier for non-combatant vessels. Requirements and equipment are most often the same as in combatant vessels which supports the machinery development also for combat vessel use. The need to renew the fleet with new technology makes offshore patrol vessel markets in my opinion the market area in non-commercial vessels which Wärtsilä should focus on.

Naval administrations can decide which rules to apply or use. When signing contracts, all requirements and rules to be used must be precisely specified to avoid misunderstandings.

REFERENCES

Wärtsilä history, 2018. History. Referred 23.05.2018. https://www.wartsila.com/about/history

Wärtsilä. 2018. Wärtsilä Corporation Annual Report 2018. Referred 30.4.2019. https://www.wartsila.com/media/news/12-02-2019-wartsila-corporation-s-annual-report-2018-published-2378491

Global security, n,d. European shipbuilding industry. Referred 25.05.2018. https://www.globalsecurity.org/military/world/europe/industry-shipbuilding.htm

Saunders, S. 2018. Jane's Fighting Ships. Referred 20.04.2018

Wikipedia, 2018. FS Jean Bart. Referred 24.05.2018. https://en.wikipedia.org/wiki/French_frigate_Jean_Bart

Military Factory. FS Forbin. Referred 24.05.2018. https://www.militaryfactory.com/ships/detail.asp?ship_id=FS-Forbin-D620

The blue-prints. HMDS Iver Huitfelt. Referred 26.05.2018. https://www.the-blueprints.com/blueprints/ships/ships-other/61509/view/hmds_iver_huitfeldt_f361_frigate/

Dmitryshulgin, 2015. Class 125 Frigate. Referred 30.5.2018. http://www.dmitryshulgin.com/tag/f223-nordrhein-westfalen/

Pinterest. HMS Bulwark. Referred 30.5.2018. https://www.pinterest.com.au/pin/371054456791098871/

Durden, 2015. Mistral Class. Referred 1.6.2018. https://www.zerohedge.com/news/2015-05-26/russia-tells-france-it-gives-mistral-ship-deal

Laitanen, S, 2014. Coast Guard Vessel Turva. Referred 2.6.2018. http://www.doria.fi/bitstream/handle/10024/117879/Laitanen_SJ.pdf;jsessionid=22A26121E796EA04D07BACF9A7EDB092?sequence=2

Icelandic Coast Guard, 2014. Coast Guard Vessel Thor. Referred 2.6.2018. http://www.lhg.is/media/skip/thor/VSTHOR_FOLDER_ENS.pdf

International Maritime Organization. Air Pollution. Referred 15.6.2018. http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Default.aspx

INSA, 2019. ANEP77, Naval Ship Code, edition G, Version 2. Referred 2.4.2019. http://s3.spanglefish.com/s/22631/documents/safety-specifications/anep-77-ed-f-v-1.pdf

Safety4sea, 2011. NSCA. Referred 16.6.2018. https://safety4sea.com/new-chairman-for-naval-ship-classification-association/

INSA, 2018. Naval Ship Code, ANEP77. Referred 16.6.2018. http://www.navalshipcode.org/naval-ship-code/

Naval Ship Code, 2014. Referred 20.6.2018. http://www.navalshipcode.org/naval-ship-code/

Ship Science & Technology, 2017. An Introduction to NATO Standard ANEP (Allied Naval Engineering Publication) 77 and Its Application to Naval Ships. Referred 27.6.2018. https://www.shipjournal.co/index.php/sst/article/view/153/442

Online conversion, n,d. g/kWh to l/h. Referred 29.4.2019. https://onlineconversion.vbulletin.net/forum/main-forums/convert-and-calculate/14370-convert-g-kwh-to-l-h

Wärtsilä, 2017.Wärtsilä 31, product guide, 3.2. Referred 29.4.2019. https://www.wartsila.com/docs/default-source/product-files/engines/ms-engine/product-guide-o-e-w31.pdf?utm_source=engines&utm_medium=dieselengines&utm_term=w31&utm_content=productguide&utm_campaign=msleadscoring

MTU, 2010. Diesel Engines 20V 4000 M93L. Referred 29.4.2019. http://www.mtu-allison.com.ar/pdf/20V_4000_M93.pdf

Rolls-Royce, 2012. Te MT7 Gas Turbine. Referred 29.4.2019. https://www.rolls-royce.com/~/media/Files/R/Rolls-Royce/documents/customers/marine/mt7-brochure.pdf

Wärtsilä, 2018. Product portfolio, Engines & Generating sets. Referred 3.7.2018. https://www.wartsila.com/products

NATO, 2018. NATO logistics handbook, chapter 15. Referred 6.7.2018. https://www.nato.int/docu/logi-en/1997/lo-15a.htm

Bartis J.T. & Van Bibber.L, 2011. Alternative Fuels for military applications. Referred 7.7.2018. https://www.rand.org/content/dam/rand/pubs/monographs/2011/RAND_MG969.pdf

Saunders, S. 2018. Jane's Fighting Ships. Referred 10.7.2018

Maxdefense, 2013. An in-depth look at the Philippine Navy Frigate program of 2013. Referred 12.7.2018. http://maxdefense.blogspot.com/2013/05/an-in-depth-look-at-philippine-navy.html

Global security, n,d. Hybrid combined propulsion systems. https://www.globalsecurity.org/military/systems/ship/systems/hybrid-intro.htm

Wikipedia, 2018. Principle of a CODAG system, with two speed diesel gearboxes. Referred 10.7.2018. https://en.wikipedia.org/wiki/Combined_diesel_and_gas

Naval technology, n,d. Nansen class Anti-Submarine Warfare Frigates. Referred 12.7.2018. https://www.naval-technology.com/projects/nansen/

RENK, n,d. Combined propulsion systems. Referred 13.7.2018. https://www.renk-ag.com/en/products-and-service/products/marine-propulsion-units/hybrid-propulsion-systems/combined-propulsion-systems/

Wordpress, 2018. F125 Baden-Württemberg Class Frigate, Germany. Referred 15.7.2018. https://thaimilitaryandasianregion.wordpress.com/2015/11/25/f125-class-frigate-germany/

Revolvy, n,d. Combined diesel-electric and gas. Referred 18.7.2018. https://www.revolvy.com/page/Combined-diesel%252Delectric-and-gas

Jane’s, n,d. Are trends electric? https://www.janes.com/images/assets/483/50483/Are_trends_electric_New_naval_power_and_propulsion_generations_emerge.pdf

Seaforces, n,d. Type 125 Baden-Wurttemberg class Frigate. Referred 19.7.2018. https://www.janes.com/images/assets/483/50483/Are_trends_electric_New_naval_power_and_propulsion_generations_emerge.pdf

Ipfs, n,d. FREMM multipurpose frigate. Referred, 19.7.2018. https://ipfs.io/ipfs/QmXoypizjW3WknFiJnKLwHCnL72vedxjQkDDP1mXWo6uco/wiki/FREMM_multipurpose_frigate.html

MTU onsite energy, n,d. Diesel generator sets. Referred 20.7.2018. https://www.mtuonsiteenergy.com/products/diesel-generator-sets/mtu-4000-ds/

Wärtsilä, 2018. Wärtsilä generating sets. Referred, 20.7.2018 https://www.wartsila.com/products/marine-oil-gas/engines-generating-sets/generating-sets/wartsila-genset-20

Buckingham, J. Geared Electric Propulsion. Referred 20.7.2018. https://www.bmtdsl.co.uk/media/6557386/BMTDSL-SCC-Geared-Electric-Paper-(SCC-Nov-16).pdf

MTU Onsite Energy, 2018. Diesel generator set MTU 16V4000DS2250 specifications. Referred 20.7.2018. https://www.mtuonsiteenergy.com/fileadmin/fm-dam/mtu_onsite_energy/1_products/spec-sheets/Diesel_60Hz_DCCP/MTU16V4000DS2250_2045kW_DCCP.pdf

MTU Onsite Energy, 2018. Diesel generator set MTU 20V4000DS3250 specifications. Referred 20.7.2018. https://www.mtuonsiteenergy.com/fileadmin/fm-dam/mtu_onsite_energy/1_products/spec-sheets/diesel-generator-sets/FN/4000_new/Standby_Power_3D/FC/32310241_OE_spec_MTU20V4000DS3250_FC_60Hz_1_15.pdf.

Wärtsilä, 2018. Wärtsilä Solutions for Marine and Oil & Gas Markets, pages 72 and 74. Referred 2.3.2019. https://cdn.wartsila.com/docs/default-source/marine-documents/segment/brochure-marine-solutions-2018.pdf?sfvrsn=658adc45_50

Ohmeyer H.F, 2012. Propulsion System Choices for modern Naval Vessels. Referred 3.9.2018. https://higherlogicdownload.s3.amazonaws.com/SNAME/3514e45e-10da-4cec-af00-5a1b541dc923/UploadedFiles/ModernNaval%20Solutions_2final.Ohmayer.Nov%202012c.pdf

Defence database, n,d. Iver Huitfeldt class. Referred 13.8.2018. https://defencedb.com/profile_details.php?item_id=127

MTU online, 2018. Diesel engines for corvettes and frigates, page 31. Referred 15.8.2018. https://mtu-online-shop.com/media/files_public/eeba80cbfe219368ec0ddf72daf016b5/3190141_MTU_Marine_SalesProgram.pdf

Wärtsilä Solutions, 2017. Wärtsilä Solutions for Marine and Oil & Gas Markets, pages 52, 53, 54. Referred 16.8.2018.

Acamadia, n,d. Full electric ship propulsion based on a flying capacitor converter and an induction drice gear. Referred 18.8.2018. https://www.academia.edu/33460767/Full_electric_ship_propulsion_based_on_a_flying_capacitor_converter_and_an_induction_motor_drive

Apsley, J.M, 2009. Propulsion drive models for full electric marine propulsion systems. Referred 21.8.2018. https://www.research.manchester.ac.uk/portal/files/29600786/POST-PEER-REVIEW-PUBLISHERS.PDF

EastWest Marine Consulting, 2018. Electrical Propulsion. Referred 28.8.2018. https://www.ewmarine.info/english/e-start/e-electrical-propulsion/

Save the Royal Navy, 2016. Putting te Type 45 propulsion problems in perspective. Referred 1.9.2018. https://www.savetheroyalnavy.org/putting-the-type-45-propulsion-problems-in-perspective/

Ficci, n,d.. Integrated full electric propulsion for Indian Navy, expectations from defence industry. Referred 15.9.2018. http://ficci.in/events/22716/ISP/2-Capt-Lavneesh-Dhawan-Navy.pdf

Schuddebeurs, J, 2014. De-risking Integrated Full Electric Propulsion (IFEP) vessels using advanced modelling and simulation techniques. Referred 20.9.2018. https://www.researchgate.net/publication/312039289_De-risking_Integrated_Full_Electric_Propulsion_IFEP_vessels_using_advanced_modelling_and_simulation_techniques/figures?lo=1

Ingeteam, n.d. PTI/PTO Hybrid Electrical Drives. https://www.ingeteam.com/Portals/0/Catalogo/Sector/Documento/SSE_2655_Archivo_pc06ippt01-.pdf

Hoedemaker, C, 2017. Battery aging in full electric ships. Referred 1.10.2018. https://repository.tudelft.nl/islandora/object/uuid%3A81aee798-31bc-4628-82a7-ab03937d1161

Zarbock, 2009. Controllable pitch propellers for future warships and mega yatchts. Referred 3.10.2018. http://www.marinepropulsors.com/proceedings/MA3-3-Zarbock%20-%20Controllable%20Pitch%20Propellers%20for%20Future%20Warships%20and%20.pdf

Naval Technology, n.d. FREMM European Multimission Frigate, France/Italy. Referred 5.10.2018. https://www.naval-technology.com/projects/fremm/

Marine insight, 2019. Propeller, Types of Propellers and Construction of Propellers. Referred 30.4.2019. https://www.marineinsight.com/naval-architecture/propeller-types-of-propellers-and-construction-of-propellers/

Wärtsilä, 2018. Wärtsilä Controllable Pitch Propeller Systems. Referred 1.11.2018. https://www.wartsila.com/products/marine-oil-gas/propulsors-gears/propellers/wartsila-controllable-pitch-propeller-systems

Wärtsilä, 2016. Propulsion Solutions for Frontline Combatants. Referred 3.11.2018. https://cdn.wartsila.com/docs/default-source/marine-documents/segment/brochure-navy-propulsion-solutions-frontline-combatants.pdf?sfvrsn=2532bf45_4

ForcesDz, n.d. MEKO A-200AN. Referred 5.11.2018 https://www.forcesdz.com/viewtopic.php?t=245&start=1455

Saarinen, V, 2013. Propeller arrangement CGV Turva. The owner of the image has given permission to use the image. Referred 8.11.2018

Saarinen, V, 2018. Information and permission for their use in table 6. has been obtained from Chief Engineer V.Saarinen.

Prenc R, CuculicA, Baumgartner I, 2016. Advantages of using a DC power system onboard Ship. Referred 15.11.2018. https://www.tandfonline.com/doi/full/10.1080/25725084.2018.1490239

ScienceDiect, 2017. Progressing towards DC electrical systems for marine vessels. Referred 17.11.2018. www.Sciencedirect.com

Tandfonline, 2018. DC-grid systems for ships: a study of benefits and technical considerations, Table 3. Referred 18.11.2018. https://www.tandfonline.com/doi/full/10.1080/25725084.2018.1490239

Everyspec, 2018. MIL-STD-1399-SECT-300_PART1, MIL-STD-1399-SECT-300_PART-2. Referred 20.11.2018. http://everyspec.com/MIL-STD/MIL-STD-1300-1399/MIL-STD-1399-SECT-300_PART-2_55834/

Work, F.W, 2016. Opportunities for Improved Warship Energy Efficiency: A Canadian Patrol Frigate's Operational Energy Use Patterns. Referred 1.12.2018. https://dash.harvard.edu/bitstream/handle/1/33797407/WORK-DOCUMENT-2016.pdf?sequence=1

Maynard, 2015. The cost of speed. Rederred 10.12.2018. https://www.geaviation.com/sites/default/files/GE-cost-of-speed.pdf

Name 591, n.d. Concept Design of an Offshore Patrol Vessel for the Canadian Coast Guard. Referred 15.12.2018. http://name2-engineering.sites.olt.ubc.ca/files/2015/08/Offshore-Patrol-Vessel-for-CCG.pdf

Research gate, 2018. A Study on the Statistical Calibration of the Holtrop and Mennen Approximate Power Prediction Method for Full Hull Form, Low Froude Number Vessels. www.researchgate.net

Saarinen, V, 2018. Information and permission for their use in table 8. has been obtained from Chief Engineer V.Saarinen.

Ingeteam, n.d. PTI/PTO Hybrid Electrical Drives. https://www.ingeteam.com/Portals/0/Catalogo/Sector/Documento/SSE_2655_Archivo_pc06ippt01-.pdf

BMT Defence Services, n.d. BMT VENATOR-110 Frigate. Referred 17.12.2018. http://www.bmtdsl.co.uk/bmt-design-portfolio/warships/bmt-venator-110-frigate/

Saunders, S. 2018. Jane's Fighting Ships. Referred 18.12.2018

Defence IQ, 2019. The growing market for offshore patrol vessels. Referred 1.4.2019. https://www.defenceiq.com/naval-maritime-defence/articles/the-growing-market-for-offshore-patrol-vessels-report

Rajavartiolatos, 2014. The Finnish Border Guard's new offshore patrol vessel, OPV Turva, is ready for duty. Referred 19.12.2018. https://www.raja.fi/facts/news_from_the_border_guard/1/0/the_finnish_border_guard_s_new_offshore_patrol_vessel_opv_turva_is_ready_for_duty_54440

Navy Recognition, 2015. Russia Navy Orders Four Project 03182 Small Arctic Sea Tankers From Two Shipyards. Referred 20.12.2018. http://www.navyrecognition.com/index.php/news/defence-news/year-2015-news/july-2015-navy-naval-forces-defense-industry-technology-maritime-security-global-news/2882-russian-navy-orders-four-project-03182-small-arctic-sea-tankers-from-two-shipyards.html

Royal Canadian Navy, 2015. Arctic and Offshore Patrol Ship Project. Referred 29.12.2018. http://www.navy-marine.forces.gc.ca/en/fleet-units/aops-home.page

Thai Military and Asian Region, 2018. Harry DeWolf -class offshore patrol vessel - Canada. Referred 20.1.2019. https://thaimilitaryandasianregion.word-press.com/2016/02/02/harry-dewolf-class-offshore-patrol-vessel-canada/

CMN, n.d. Vigilante 1400 CL79. Referred 1.2.2019. https://cmn-group.com/prod-ucts-and-services/military-vessels/vigilante/vigilante-1400-cl79/

Vard marine, 2019. VARD 7 100, Referred 5.2.2019. https://vardmarine.com/gal-lery/vard-7-100/

ANEP77, 2014. ANEP77, Edition G, version 2, PART3-VI-41, 8.9. Referred 2.4.2019

ASTM, 2018. Standard Test Method for Shock Testing of Structural Insulation of A-Class Divisions Constructed of Steel and Aluminum. Referred 25.2.2019 https://www.astm.org/Standards/F2877.htm

Brazell, J.R, Bruce, D.K, Mayer, G.T, n.d. Shock Design of the MK 49 Ship's Inertial Navigation System. Referred 1.3.2019. https://www.taylordevices.com/cus-tom/pdf/tech-papers/85-Shock%20Design_MK49Isolation.pdf

EverySpec, n.d. MIL-S-901D. Referred 5.3.2019. http://everyspec.com/MIL-SPECS/MIL-SPECS-MIL-S/MIL-S-901D_14581/

Sebert, 2018. Overwiew of Standards. Referred 20.2.2019. https://sebert.nl/en/over-view-of-standards

Nain H, 2013. Management of Naval Vessel's Electromagnetic Signatures: A review of Sources and Countermeasures. Referred 13.3.2019. https://www.re-searchgate.net/publication/263315668_Management_of_Naval_Vessel%27s_Elec-tromagnetic_Signatures_A_Review_of_Sources_and_Countermeasures

APPENDIX 1

SUMMARY OVER PRESENT EUROPEAN DESTROYERS, FRIGATES, CORVETS, COMBAT SUPPORT SHIPS AND COAST/BORDER GUARD PATROL VESSELS (Jane's fighting ships 2017-2018)

TYPE/NUMBER	COUNTRY	DISPLACEMENT	LENGHT (M)	BUILDING YEAR	SPEED (kt)	MAIN ENGINE POWER OUTPUT	RANGE (NM)
Destroyers							
2 Destroyer, Forbin Class	France	7163	152,9	2005-2006	31, 18 with Diesel	47 MW Gas turbines, 9,95 MW Diesel	7000 NM at 18 kt
8 Destroyer, Aquitane Class	France	6096	142,2	2010-2020	27,5	32 MW Gas turbines, 12,7 MW Diesel	6000 NM at 15 kt
2 Destroyer, Cassard Class	France	5080	139	1985-1988	29,5	31,75 MW Diesel	8000 NM at 17 kt
2 Destroyer, Leygues Class	France	4908	139	1975-1979	30, 20 with Diesel	38,2 MW Gas tur-bines, 8,3 MW Diesel	8000 NM at 15 kt, 2500 miles at 28 kn

3 Destroyer, Modified Georges Leygues Class	France	4989	139	1984-1988	30, 21 with Diesel	38,2 MW Gas turbines, Diesel	8000 NM at 15 kt, 2500 NM at 28 kt
2 Destroyer, Andrea Doria class	Italy	6741	152,9	2005-2007	29	41 MW Gas turbines, 8,6 MW Diesel	7000 NM at 18 kt
2 Destroyer, De La Penne class	Italy	5869	147,7	1989-1991	31, 21 with Diesel	40,3 MW Gas turbines, 9,3 MW Diesel	7000 NM at 18 kt
6 Destroyer, Daring class	United Kingdom	7570	152,4	2006-2010	31	49,7 MW Gas turbine, 4 MW Diesel	6500 NM at 18 kt
Frigates							
2 Frigate, 2M class	Belgium	3373	123,8	1988-1989	30, 21 with Diesel	25,2 MW Gas turbine, 7,2 MW Diesel	5000 NM at 18 kt
3 Frigate Iver Huidtfelt Class	Denmark	6645	138,7	2010	28	32,8 MW Diesel	--

4 Frigate, Thetis Class	Denmark	3556	112,5	1989-1991	20,8	9,39 MW Diesel	8500 NM at 15,5 kt
9 Frigate, D'estienne D'orves Class	France	1270	80,5	1978-1983	24	20,4 MW Diesel	4500 NM at 15 kt
6 Frigate, Floreal Class	France	2997	93,5	1990-1993	20	6,95 MW	10000 NM at 15 kt
4 Frigate, Brandenburg Class	Germany	5487	138,9	1992-1995	29, 21 with Diesel	38 MW Gas turbines, 8,14 MW Diesel	4000 NM at 15 kt
3 Frigate, Bremen Class	Germany	3739	130	1982-1987	30, 20 with Diesel	38 MW Gas turbines, 8,14 MW Diesel	4000 NM at 15 kt
3 Frigate, Sachsen Class	Germany	5690	143	1999-2003	29	23,5 MW Gas turbines, 14,8 MW Diesel	4000 NM at 15 kt
4 Frigate, Baden Wurttemberg Class	Germany	7136	149,5	2014-2017	26	20 MW Gas turbines, 12 MW Diesel	4000 NM at 18 kt
4 Frigate, Hydra Class	Greece	3404	117	1991-1997	31, 20 with Diesel	44,76 MW Gas turbines, 7,66 MW Diesel	4100 NM at 16 kt

9 Frigate, Elli class	Greece	3688	130,5	1979-1980	30	47,1 MW Gas turbines	4700 NM at 16 kt
10 Frigate, Bergamini class	Italy	6700	143,9	2011-2020	27	32 MW Gas turbine, 12,8 Diesel	6000 NM at 15 kt
8 Frigate, Maestrale class	Italy	3251	122,7	1981-1984	32, 21 with Diesel	37,3MW Gas turbine, 8,1MW Diesel	6000 NM at 16 kt
2 Frigate, Artigliere class	Italy	2566	113,2	1984-1985	35, 21 with Diesel	37,3 MW Gas turbine, 5,7 MW Diesel	5000 NM at 15 kt
2 Frigate, 2 M class	Netherlands	3340	123,8	1990-1994	29, 19 with Diesel	25,5 MW Gas turbine, 7,2 MW Diesel	6200 NM at 18 kt
4 Frigate, De zeven provincien class	Netherlands	6145	144,2	2000-2003	28	39 MW Gas turbine, 10 MW Diesel	5000 NM at 18 kt
5 Frigate, Fritjof Nansen class	Norway	5375	133,2	2004-2009	26	19,2 MW Gas turbine, 9 MW Diesel	4500 NM at 16 kt
2 Frigate, Oliver	Poland	3696	135,6	1978-1979	29	30,59 MW Gas turbine	4500 NM at 20 kt

Hazard Perry class							
2 Frigate, Bartolomeu Dias class	Portu-gal	3320	122,3	1992	29, 21 with Diesel	25,2 MW Gas turbine, 7,2 MW Diesel	5000 at 18 kt
3 Frigate, Vasco Da Gama class	Portu-gal	3353	115,9	1989-1990	32, 21 with Diesel	39,5 MW Gas turbine, 6,5 MW Diesel	4900 NM at 18 kt, 9600 NM at 12 kt
2 Frigate, Broadsworth class	Roma-nia	4877	146,5	1984-1986	30	44,7 MW Gas turbine	--
Frigate, Marasesti class	Roma-nia	5883	144,6	1981	27	23,5 MW Diesel	--
5 Frigate, Alvaro De Bazan class	Spain	5947	146,4	2000-2010	28	34,8 MW Gas turbine	4500 NM at 18 kt
6 Frigate, Santa Maria class	Spain	4033	137,7	1984-1993	29	30,59 MW Gas turbine	4500 NM at 20 kt
13 Frigate, Duke class	United King-dom	4267	133	1989-2000	28, 15 Die-sel-elec-tric	23,2 MW gas turbine, 6 MW Die-sel-electric	7800 NM at 15 kt

Offshore Patrol Vessels							
4 Offshore Patrol Vessel, Damen Stan Patrol	Albania	260	42,8	2007-2014	26	5,75 MW Diesel	--
2 Offshore Patrol Vessel, Castor class	Belgium	510	53,5	2014	22	5,76 MW Diesel	2000 NM at 10 kt
Offshore Patrol Vessel	Croatia	1544	73,3	1972	17	2,7 MW Diesel	--
3 Offshore Patrol Vessel, Knud Rasmussen class	Denmark	1748	71,8	2006-2015	17	5,45 MW Diesel	--
Offshore Patrol Vessel, Silmä Class	Estonia	539	48,3	1963	11	1,32 MW Diesel	--
Offshore Patrol Vessel, Kindral Kurvits Class	Estonia	1200	63,9	2012	15	4,06 MW Diesel	--
Offshore Patrol Vessel, Tjaldrid Class	Faroe Islands	660	42,1	1976	14,5	1,76 MW Diesel	--

2 Offshore Patrol Vessel, Tursas Class	Finland	1118	57,8	1986-1987	15	3,2 MW Diesel	2000 NM at 15 kt
Offshore Patrol Vessel, Turva Class	Finland	4600	95,8	2013	18	12 MW Diesel/ LNG	--
Offshore Patrol Vessel, Laperouse Class	France	996	59	1990	15	1,96 MW Diesel	5000 NM at 12 kt
4 Offshore Patrol Vessel, 4 P 400 Class	France	488	54,8	1987	23	5,88 MW Diesel	4200 NM at 15 kt
3 Offshore Patrol Vessel, Flamant Class	France	396	54,8	1995-1996	22	5,32 MW Diesel	4500 NM at 14 kt
4 x Oceanic Patrol Vessel, B2M Class	France	2300	65	2016-2017	15	--	5000 NM at 12 kt
3 Offshore Patrol vessel, Bad Bramstedt class	Germany	813	65,9	2002-2003	21,5	5,2 MW Diesel	--
Offshore Patrol	Germany	684	65,4	1988	25	6,12 MW Diesel	2000 NM at 25 kt,

Vessel, Bredstedt class							7000 NM at 10 kt
3 Offshore Patrol Vessel, Meerkatze Class	Germany	1981	72	2008-2009	19	--	--
3 Offshore Patrol Vessel, Saar 4 class	Greece	457	58	2003-2004	32	11,03 MW Diesel	1650 NM at 30 kt, 4000 NM at 17,5 kt
Offshore Patrol Vessel, Damen Stan Patrol Class	Greece	--	58	2015	25	--	--
Offshore Patrol Vessel, Vosper europatrol 250 MK1 class	Greece	244	47,3	1994	40	9,8 MW Diesel	2000 NM at 16 kt
2 Offshore Patrol Vessel, Aegir class	Iceland	1524	69,8	1967-1975	20	9,68 MW Diesel	9000 NM at 18 kt
Offshore Patrol Vessel, Thor class	Iceland	4064	93,8	2009	19,5	8 MW Diesel	--

2 Offshore Patrol Vessel, Roisin class	Ireland	1727	78,9	1999-2001	23	5 MW Diesel	6000 NM at 15 kt
3 Offshore Patrol Vessel, Mod Roisin class	Ireland	2226	89,5	2013-2016	23	5 MW Diesel	6000 NM at 15 kt
Offshore Patrol Vessel, Eithne	Ireland	1941	80,8	1983	20	5,07 MW Diesel	7000 NM at 15 kt
2 Offshore Patrol Vessel, Peacock class	Ireland	723	62,6	1984-1985	25	10,58 MW Diesel	2500 NM at 17 kt
Offshore patrol vessel, P21 class	Ireland	1036	65,2	1979	17	3,53 MW Diesel	4000 NM at 17 kt
2 Offshore Patrol Vessel, Dattilo & Diciotti	Italy	3600	94	2012-2013	17	4,58 MW Diesel	--
Offshore Patrol Vessel, Gregoretti	Italy	2153	62,6	2011	--	3,53 MW Diesel	--
4 Offshore Patrol Vessel, Saettia class	Italy	434	52,8	1985-2004	29	9,44 MW Diesel	1800 NM at 18 kt

Offshore Patrol Vessel, Valpas	Latvia	554	48,5	1971	15	1,47 MW Diesel	--
3 Offshore Patrol Vessel, Flyvefisken class	Lithuania	488	54	1989-1994	18	4,26 MW Diesel	2400 NM at 18 kt
4 Offshore Patrol Vessel	Netherlands	3810	108,4	2009-2011	22	14,4 MW Diesel	5000 NM at 16 kt
Offshore Patrol vessel, Arctic class	Norway	6401	103,7	2002	17	10 MW Diesel-electric	10000 NM at 13 kt
Offshore Patrol Vessel, Ulstein UT 512 class	Norway	3180	83	2005	19	8 MW Diesel	--
3 Offshore Patrol Vessel, Barentshav class	Norway	4064	93,2	2009-2010	20	7,46 MW, LNG/ Diesel-electric	--
3 Offshore Patrol Vessel, Nordkapp class	Norway	3353	105,5	1980-1981	21	11,9 MW Diesel	7500 NM at 15 kt
5 Offshore Patrol Vessel, Nornen class	Norway	755	47,2	2006-2007	16	1,86 MW Diesel-electric	--

Offshore Patrol Vessel, Ålesund	Norway	1379	63	1996	16	2,64 MW Diesel	--
2 Offshore Patrol Vessel, Kaper class	Poland	380	42,5	1992	17,5	3,47 MW Diesel	2800 NM at 14 kt
Offshore Patrol Vessel, Damen OPV 900	Romania	1028	66	2010	21	5,05 MW Diesel	--
3 Offshore Patrol vessel, Alboran class	Spain	1995	67	1997-2004	13	1,76 MW Diesel	20000 NM at 13 kt
4 Offshore Patrol Vessel, Descubierta class	Spain	1693	88,8	1976-1978	25	11 MW Diesel	4000 NM at 18 kt, 7500 at 12 kt
4 Offshore Patrol Vessel, Serviola class	Spain	1165	68,7	1990-1991	19	5,5 MW Diesel	8000 NM at 12 kt
6 Offshore Patrol Vessel, Meteoro class	Spain	2675	93,9	2009-2017	20,5	9 MW Diesel	8000 NM at 12 kt
3 Offshore Patrol Vessel, KBV 001 class	Sweden	5848	81,2	2009-2010	16	5,82 MW Diesel	--

Offshore Patrol Vessel, KBV 181 class	Sweden	1007	56	1990	16	2,76 MW Diesel	--
Other Warfare vessels							
2 Combat Support Ship	Denmark	6401	137	2004	23	16,63 MW Diesel	11500 NM at 14 kt
3 Amphibious assault ship, Mistral Class	France	21947	199	2004-2010	19	36,3 MW Diesel-electric	11000 NM at 15 kt, 6000 NM at 18 kt
Amphibious warfare ship, Rotterdam class	Netherlands	12955	166	1997	18	14,6 MW Diesel-electric	6000 NM at 12 kt
Amphibious warfare ship, Johan De Witt class	Netherlands	16948	176,4	2006	17	14,4 MW Diesel-electric	10000 NM at 12 kt
Amphibious Transport ship, Afonso De Albuquergue	Portugal	10668	162	2018	19	14 MW, Diesel-electric	6000 NM at 14 kt
2 Amphibious	Spain		160		20		

Transport ship, Galicia class		14037		1997-1999		9,2 MW Diesel	6000 NM at 12 kt
Amphibious Transport ship, Juan Carlos 1 class	Spain	27514	202,3	2008	21	19,8 MW Gas turbine, 15,7 MW Diesel	9000 NM at 15 kt
Helicopter carrier, Ocean	United Kingdom	22107	170	1995	19	13,5 MW Diesel electric	8000 NM at 15 kt
2 Assault ship, Albion class	United Kingdom	18797	176	2001	18	15,6 MW Diesel-electric	8000 NM at 15 kt