BUCHAREST 2018 SYMPOSIUM ON MICROGRIDS University Politehnica of Bucharest, Romania 2- 6 September 2018

Microgrid Maritime

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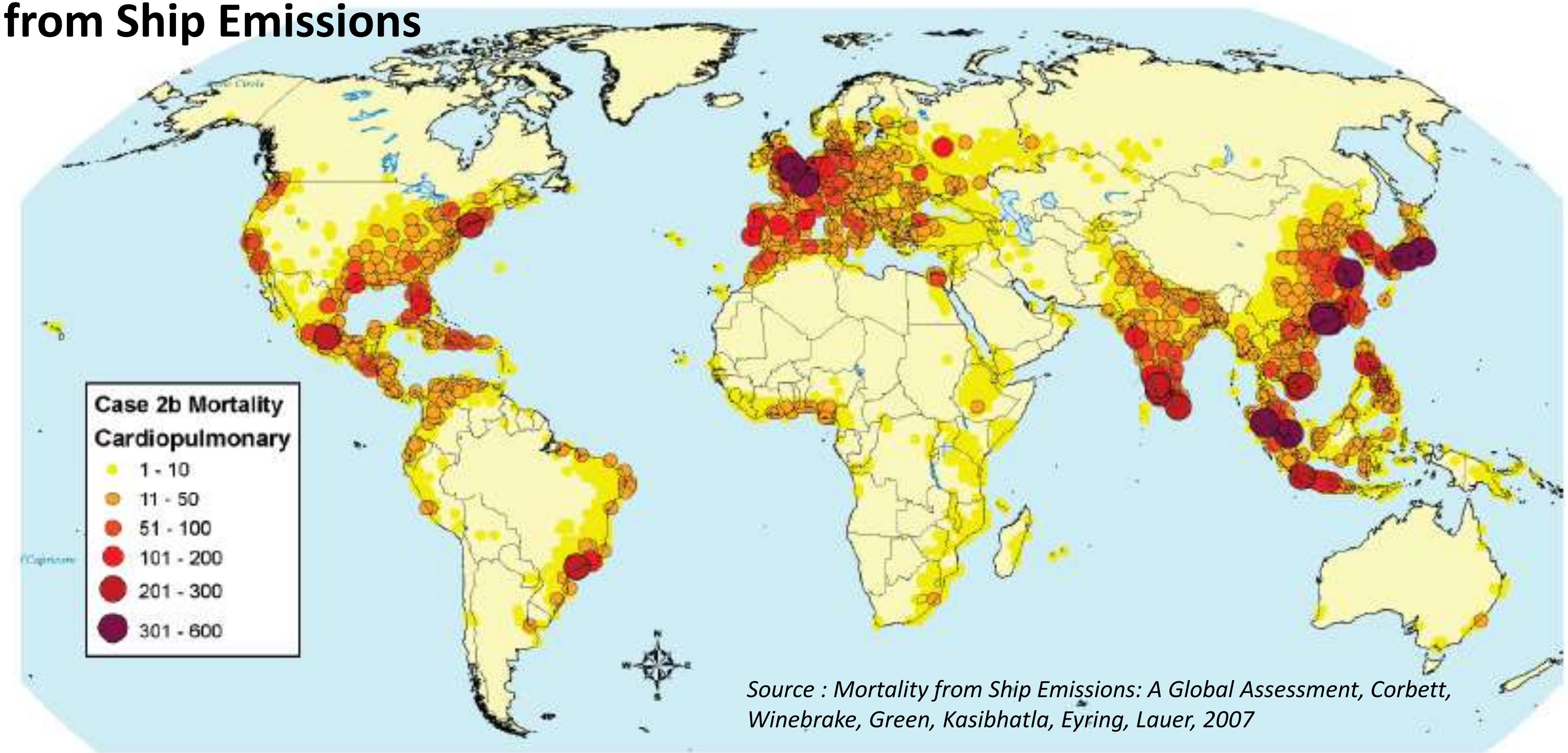
State-of-the-art of SPS

Mortality from Ship Emissions



Source : Mortality from Ship Emissions: A Global Assessment, Corbett, Winebrake, Green, Kasibhatla, Eyring, Lauer, 2007

2% … of global CO_2 emissions

15% … of global nitrogen oxide (NOx) emissions**

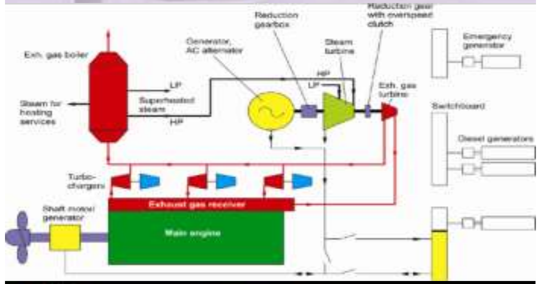
6% … of global sulfur oxide (SOx) emissions**

… are generated by ships

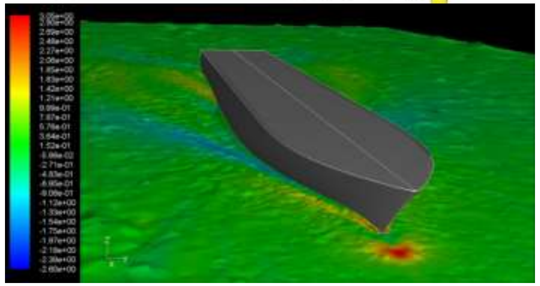
State-of-the-art of SPS

Several methods for improving fuel efficiency

LNG



Waste Heat recovery



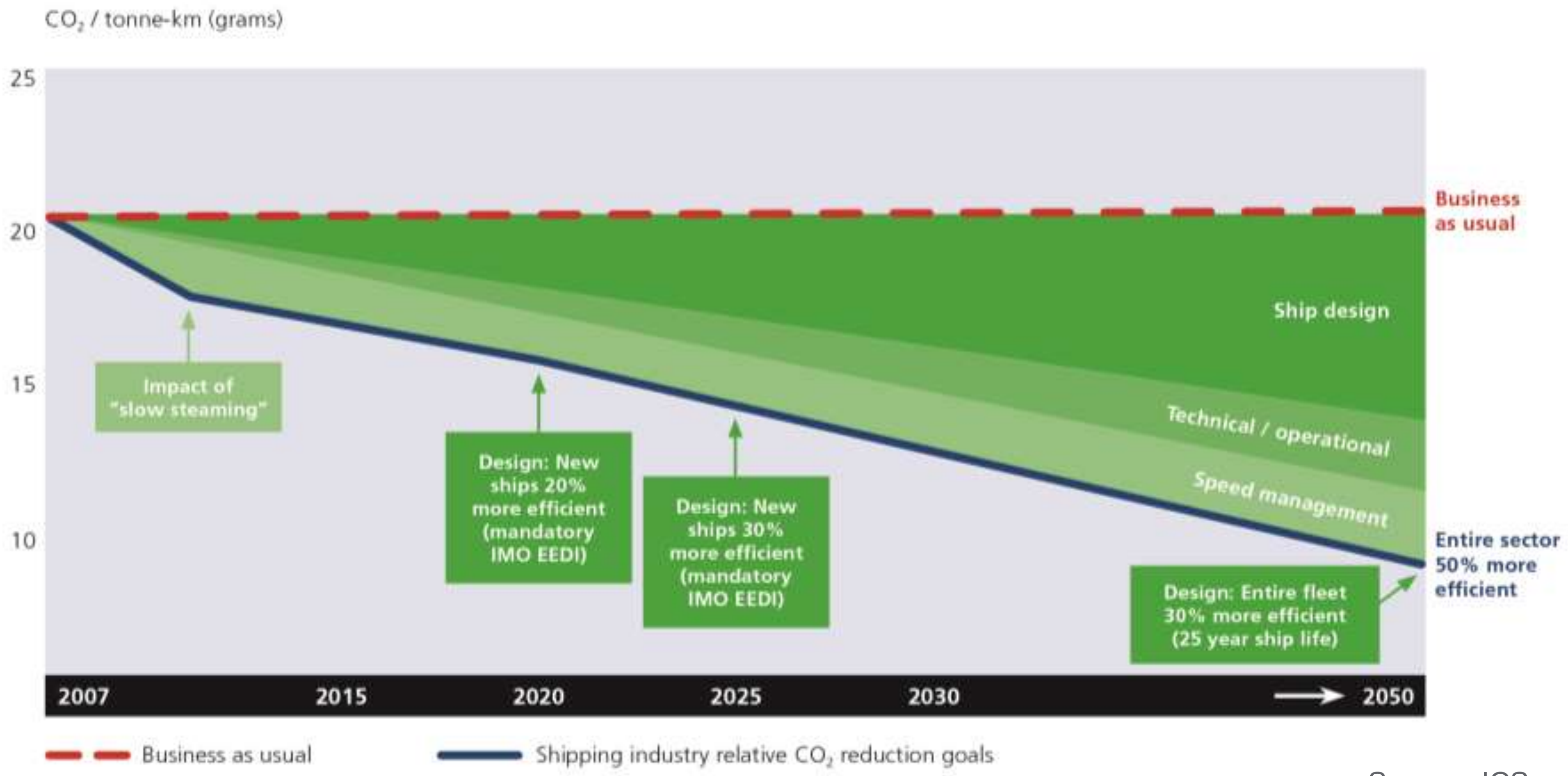
Hull optimisation

ECO upgrades

Port-to-ship Shore connection

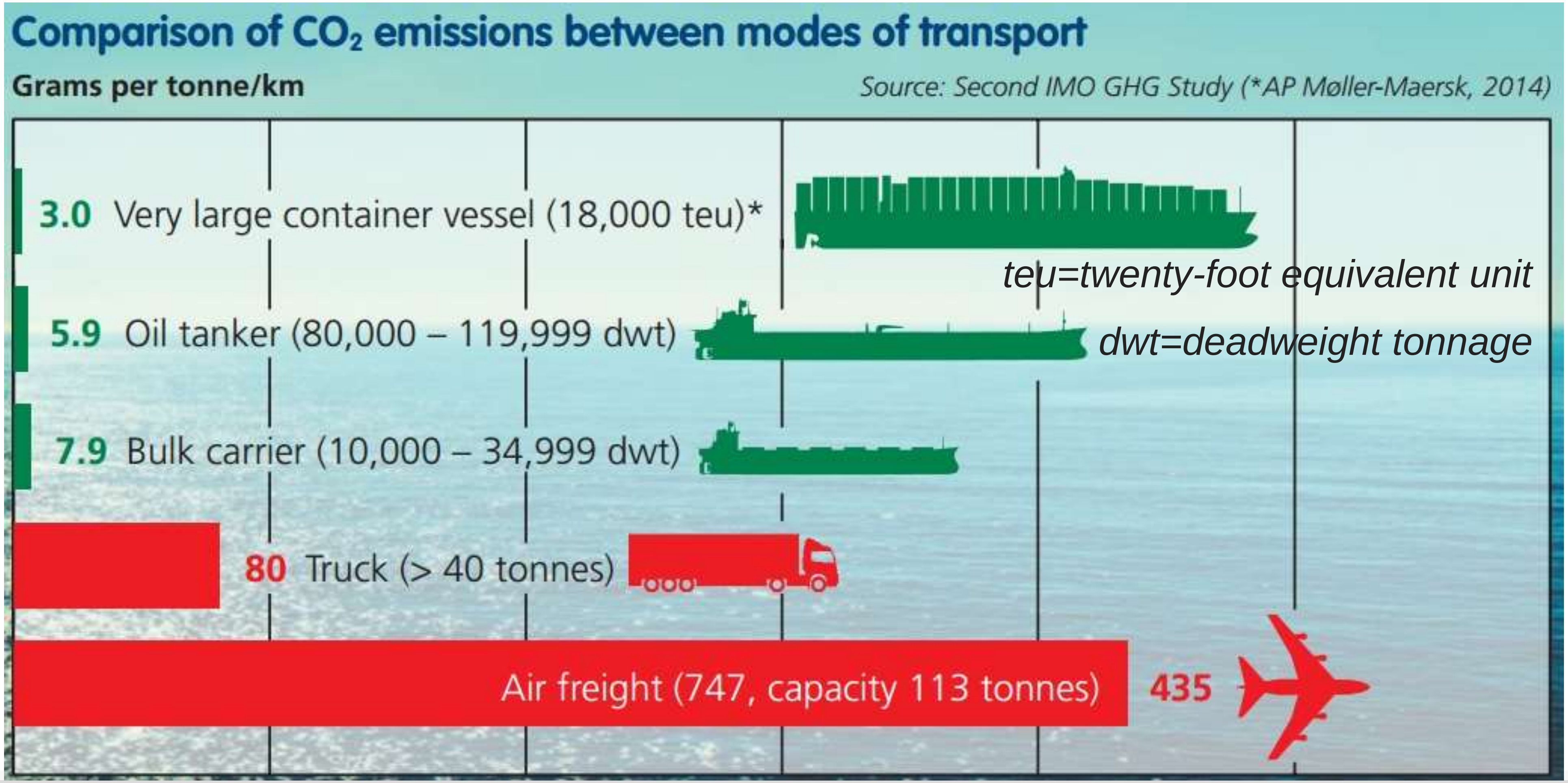
Source: Schneider Electric

Shipping's CO2 Reduction Goals



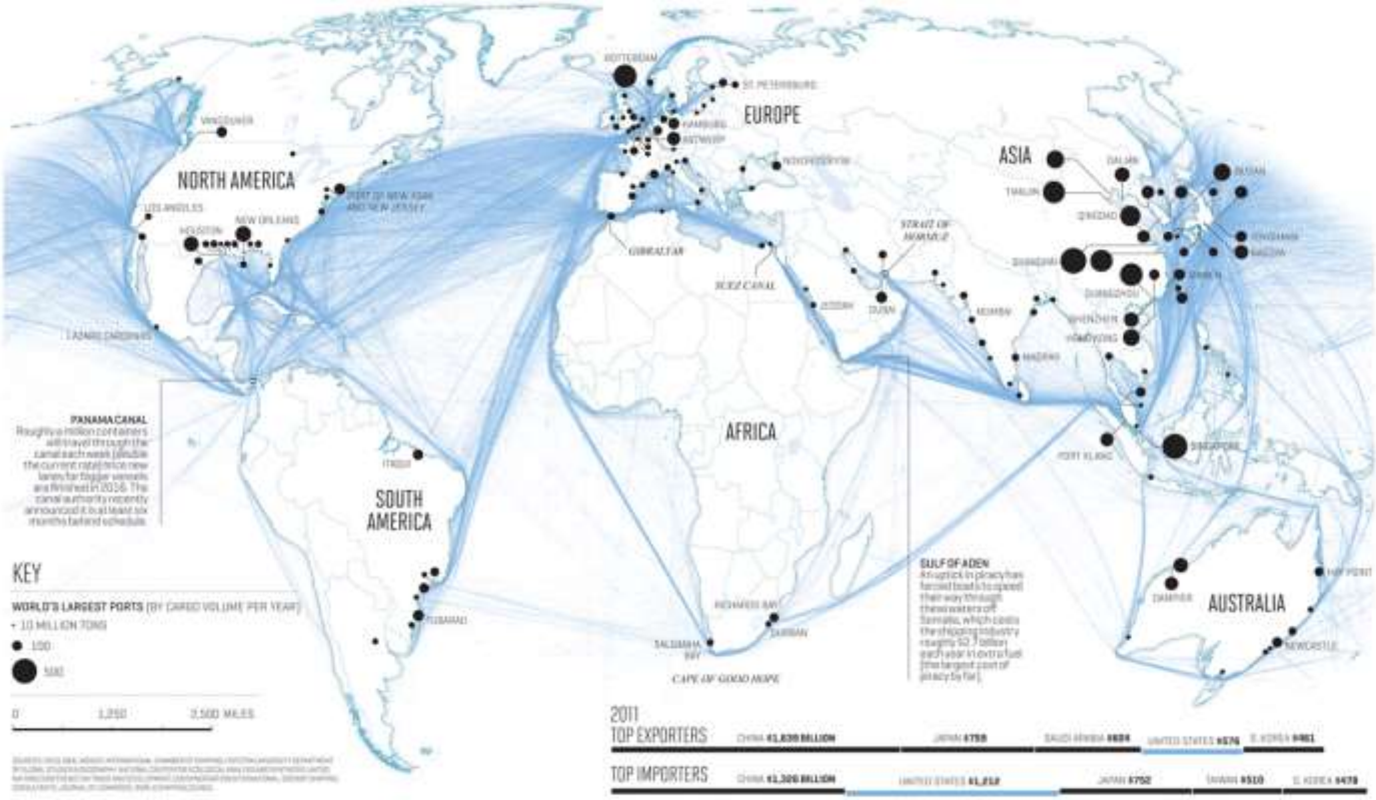
Source : ICS

State-of-the-art of SPS



State-of-the-art of SPS

Containers: now +20 million shipping containers are plying the world’s oceans

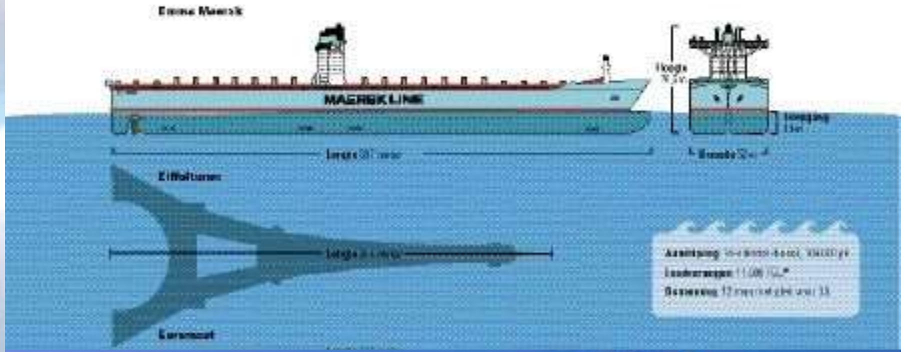


State-of-the-art of SPS

The MV Emma Mærsk officially carries 11,000 TEU (14 tons gross each)

State-of-the-art of SPS

Emma Maersk, the world's currently largest container ship in Aarhus 5-9-2006



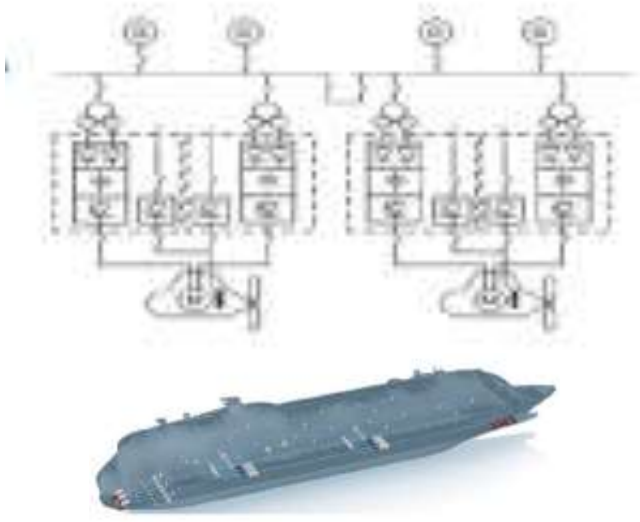
State-of-the-art of SPS

The biggest in the world:

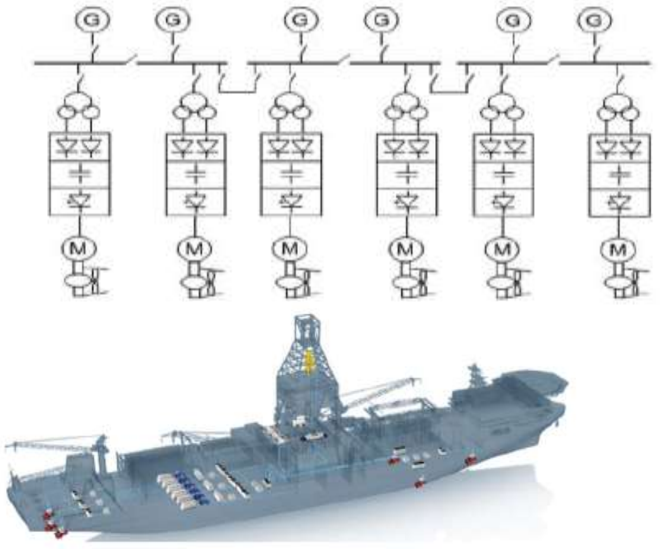
- 2,000 metric-ton fully-electric
- 70.5m long, 13.9m wide, 4.5m deep, 3.3m draft design
- Launched late 2017 in Guangzhou
- Guangzhou Shipyard International Company Ltd.
- 70.5-meter cargo boat
- Lithium battery
- Cruise for 80 kilometers
- 2h charge @ 2.4 MWh
- Top speed is 12.8 km/h

State-of-the-art of SPS

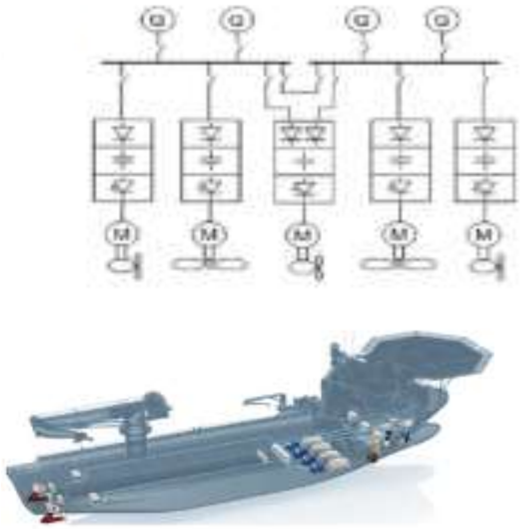
- The electric propulsion solutions applied for some of the main vessel types.
- Based on the difference requirement of the ship mission.



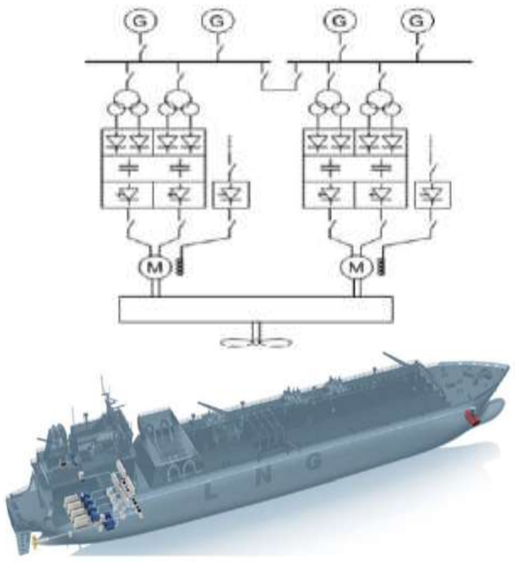
Cruise vessel



Drillship

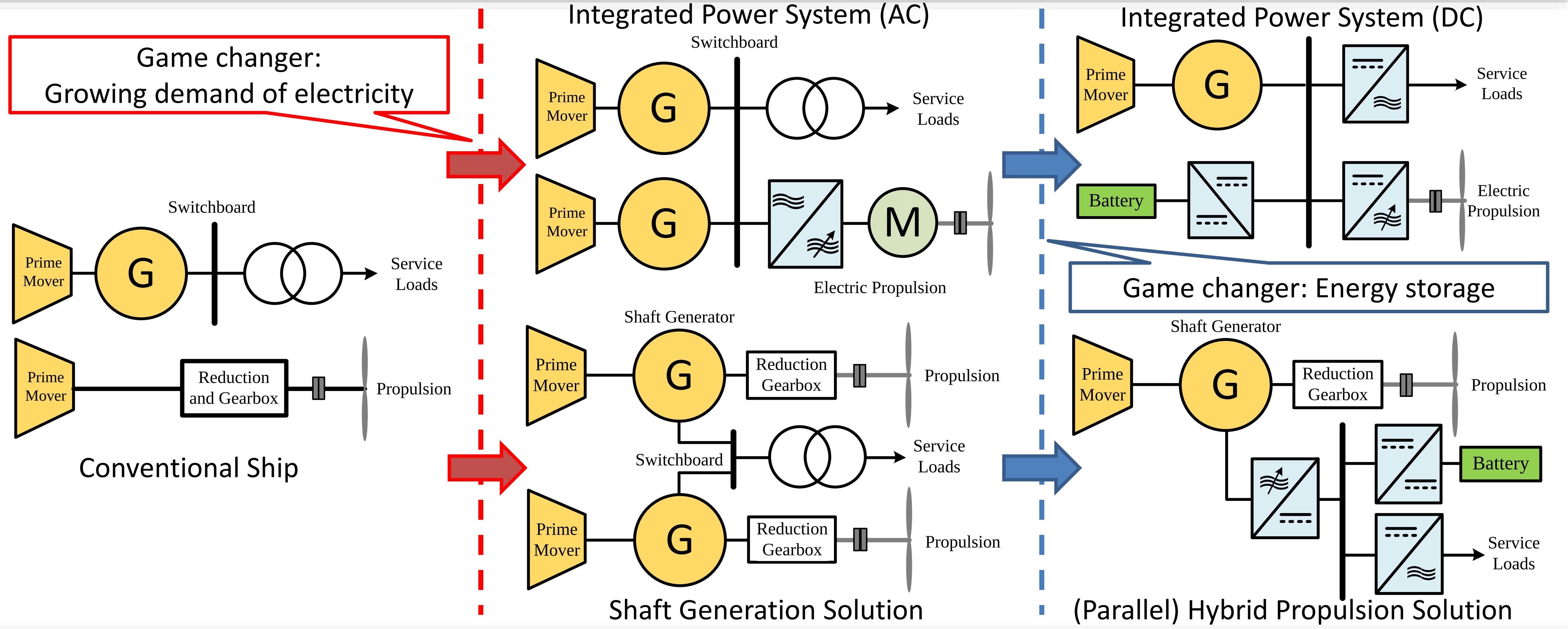


Offshore support/construction vessels

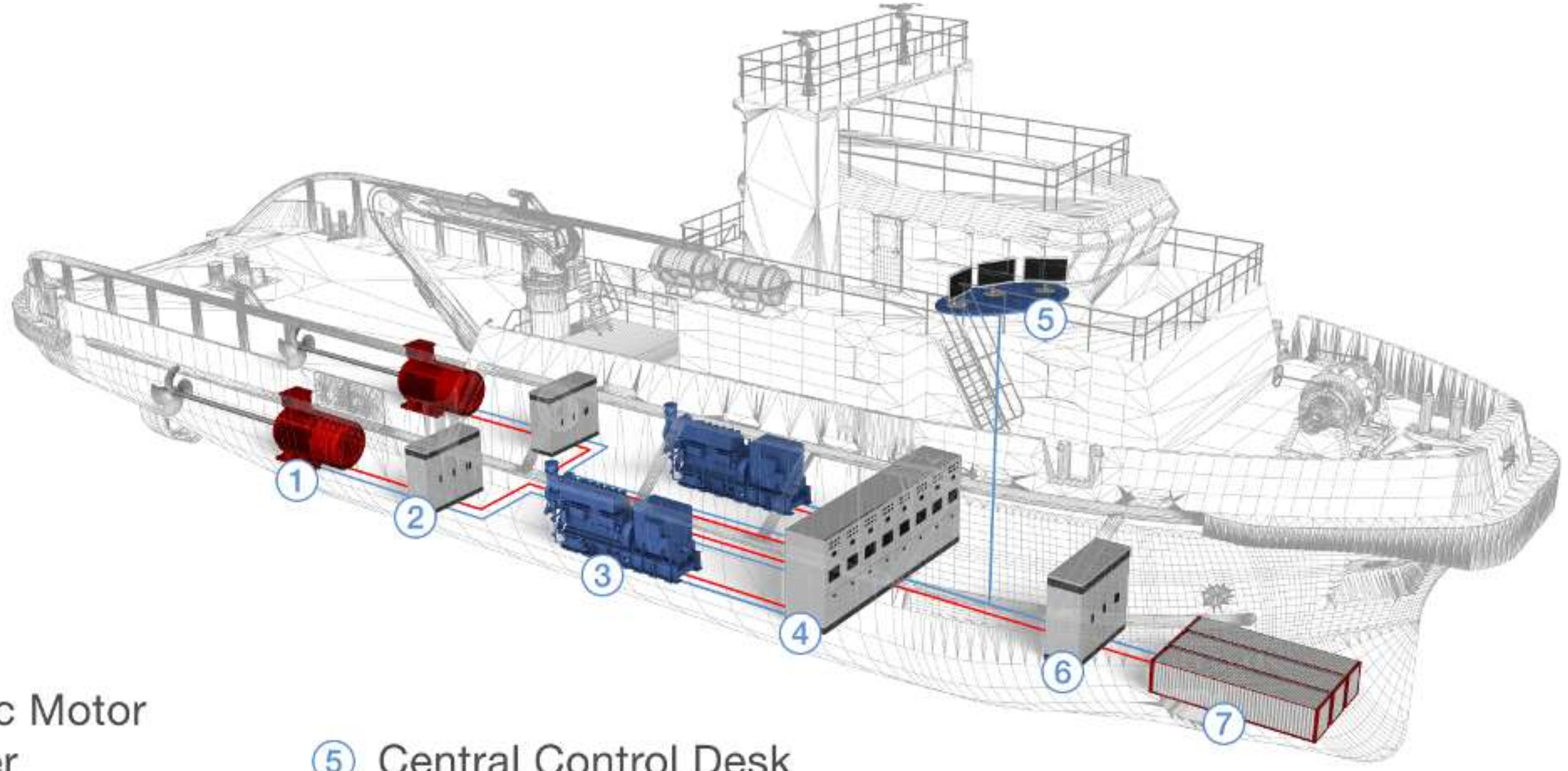


LNG Carrier

State-of-the-art of SPS



State-of-the-art of SPS



1. Electric Motor
2. Inverter
3. Engine-generator
4. Switchgear
5. Central Control Desk
6. Battery Converter
7. Battery Storage

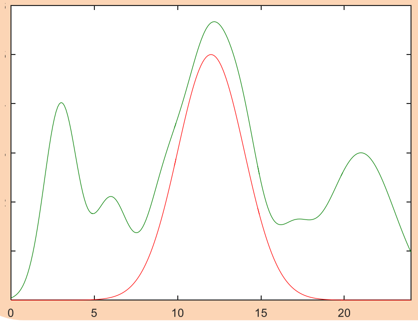
Source: Typhoon HIL

State-of-the-art of SPS

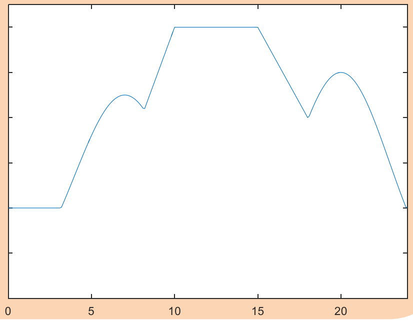
Terrestrial Microgrids V.S. Shipboard Microgrids:

Terrestrial Microgrids

Intermittent Renewables



Regular Loads



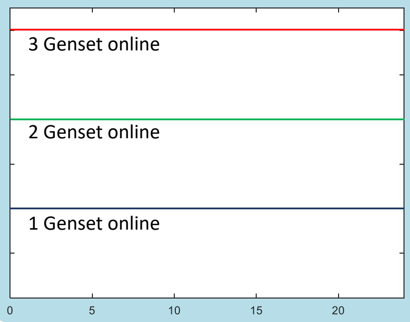
Intermittency Compensation

Mismatch in Generation & Consumption

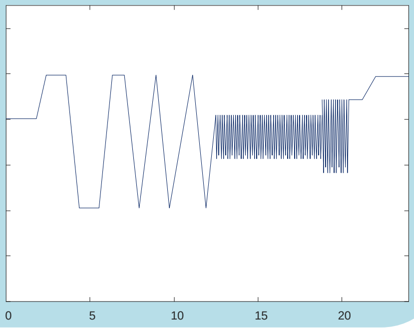
Instant Power Support

Shipboard Microgrids

Economical Generation

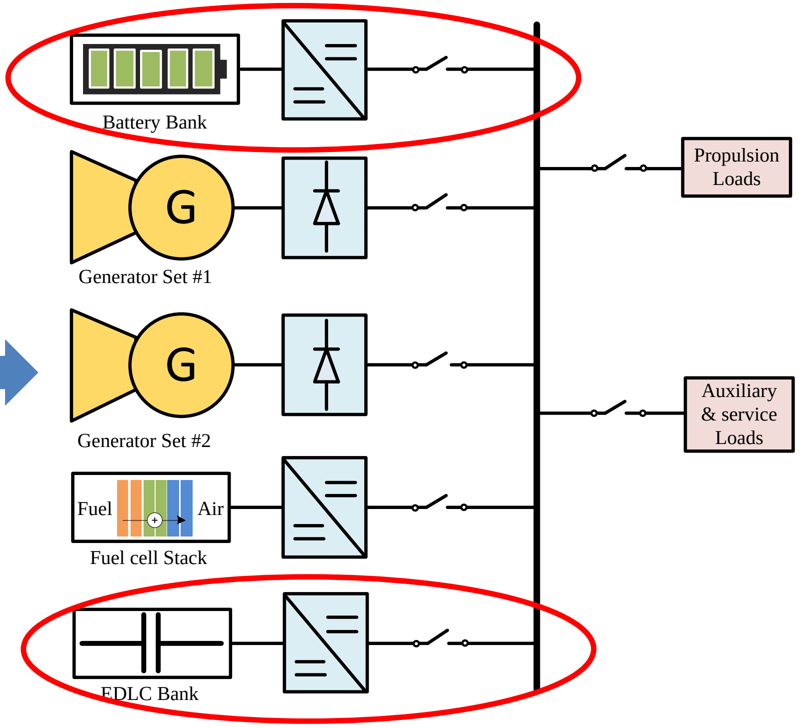


Dynamic Loads



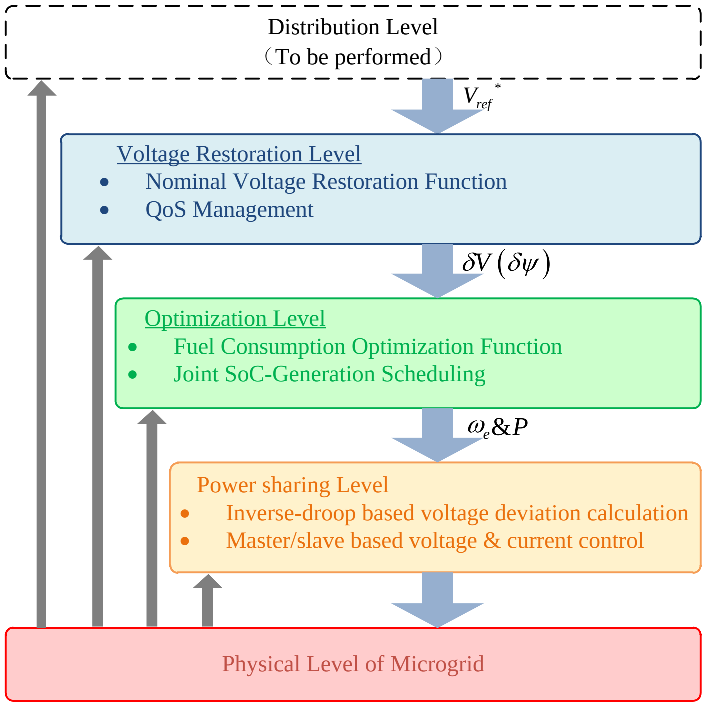
Key Point

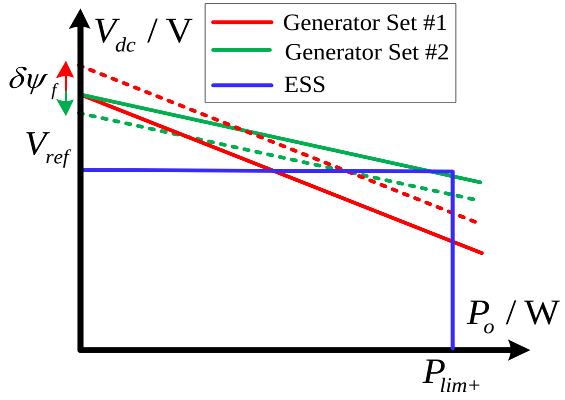
Control of Energy Storage Systems

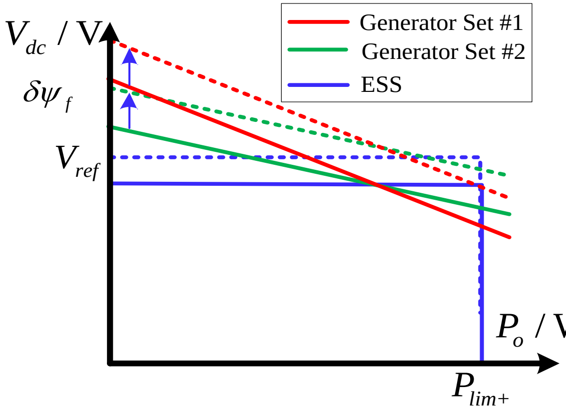


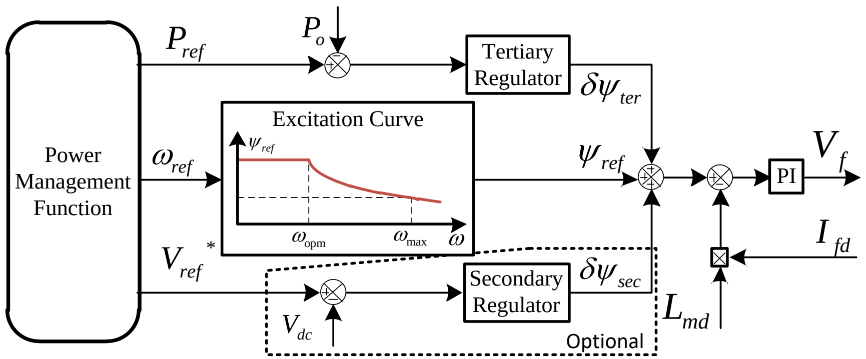
State-of-the-art of SPS

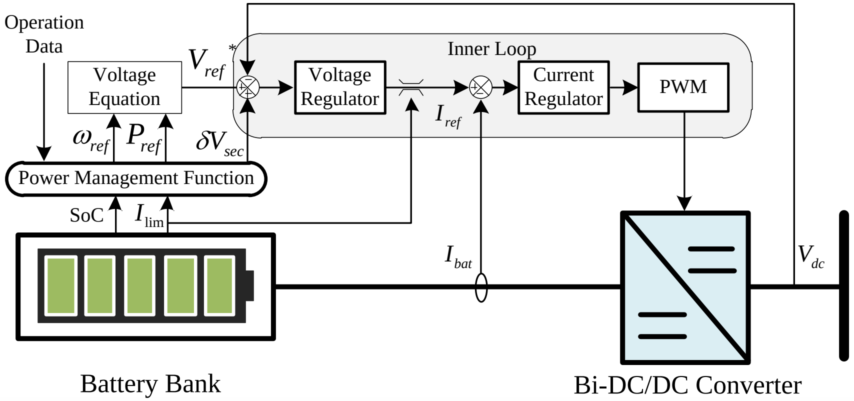
Higher levels design：







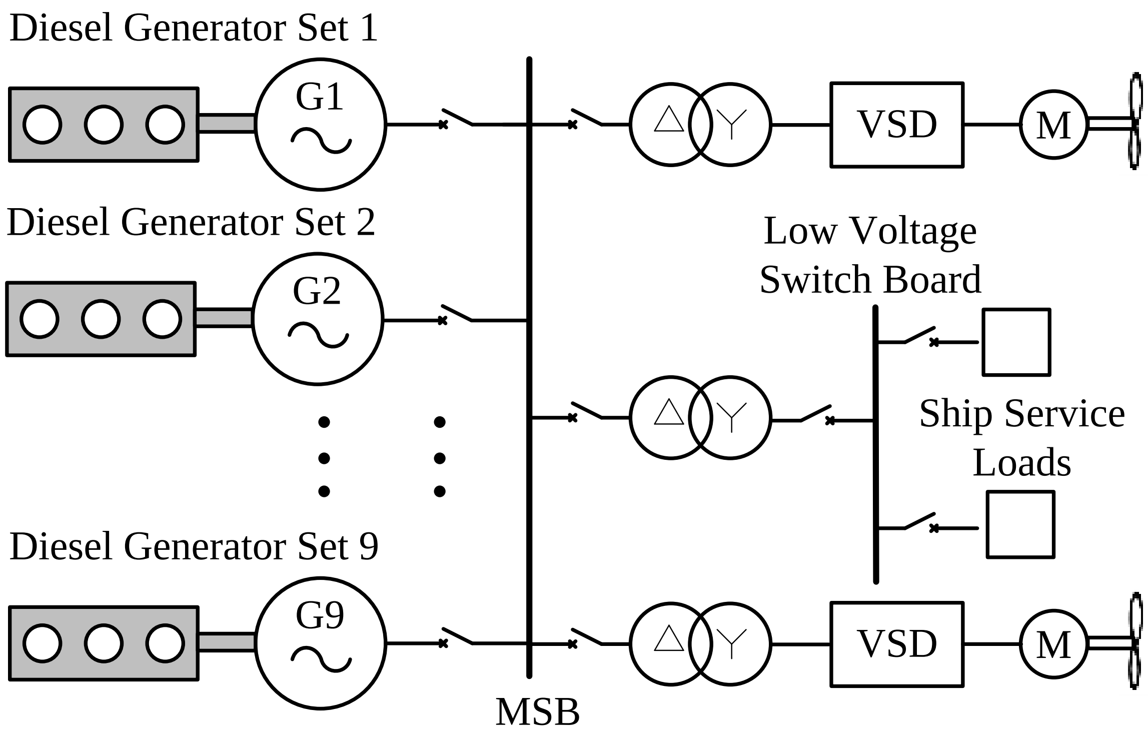




State-of-the-art of SPS

Queen Elizabeth II – cruise ship

Integrated electric propulsion configuration



16-cylinder Wärtsilä 16V46CR EnviroEngine marine diesel engines, providing 67,200 kW (90,100 hp)@514 rpm
2 General Electric LM2500+ gas turbines, total provide 50,000 kW (67,000 hp)

State-of-the-art of SPS

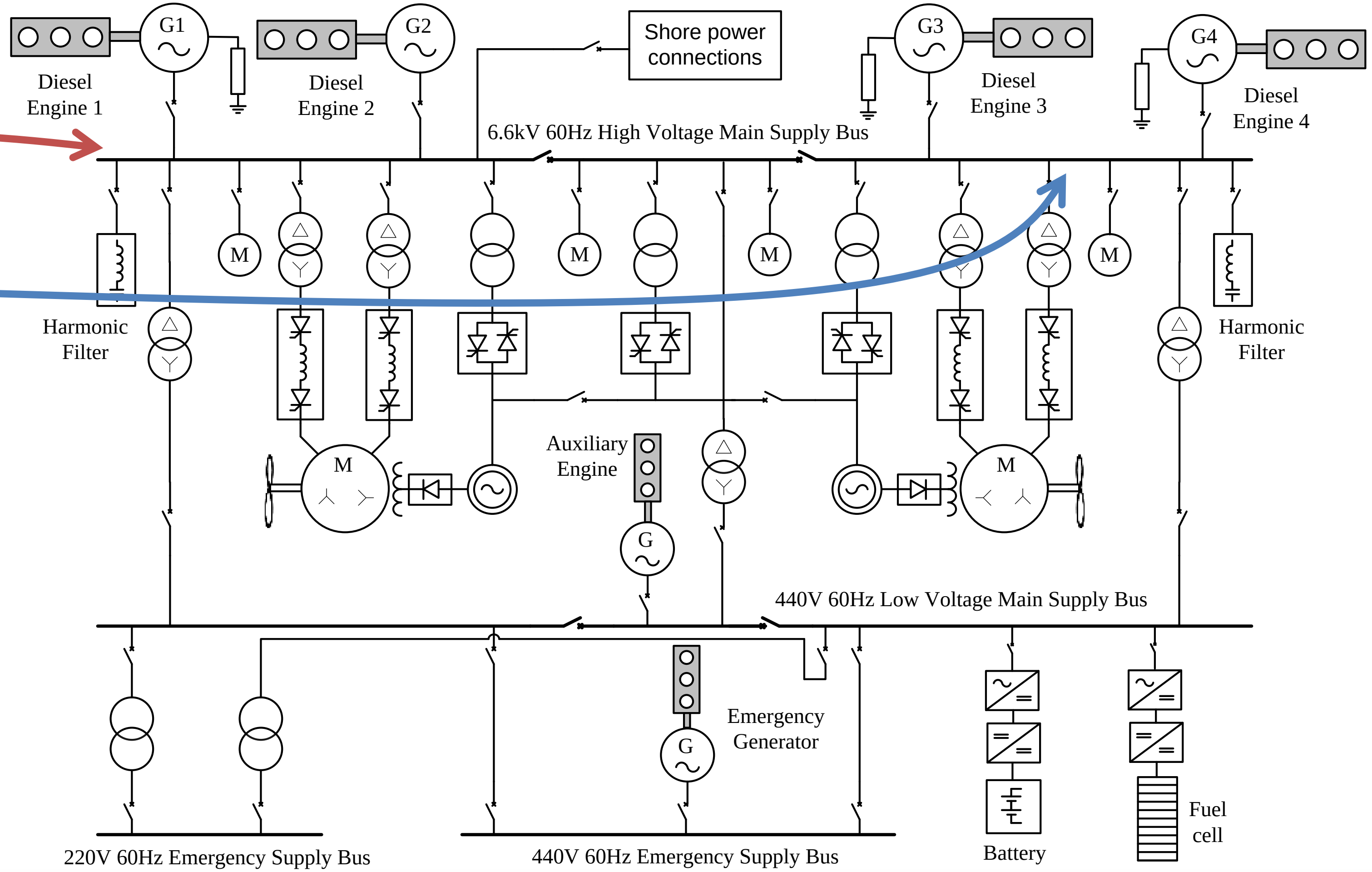
Radial AC distribution system

The 2 busses:

- port side bus
- starboard side bus

are linked with bus-tie switches.

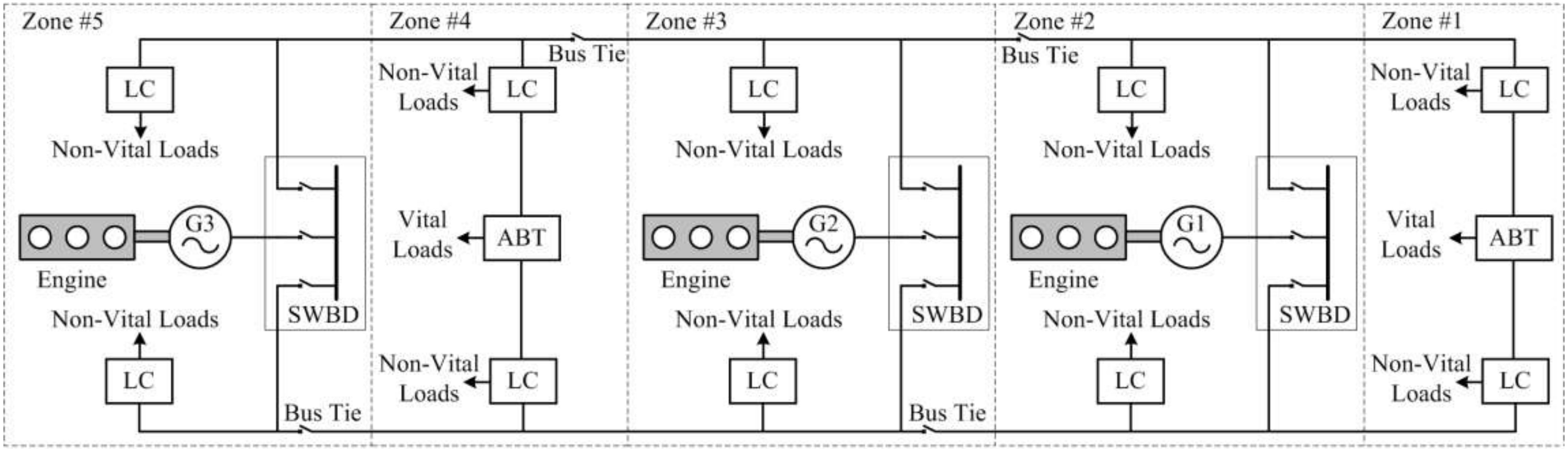
These switches can be opened to disconnect the faulty bus from the healthy bus in the event of a fault and thus potential blackouts can be prevented



Huang, K.; Srivastava, S.K.; Cartes, D.A.; Sun, L.-H. Market-based multiagent system for reconfiguration of shipboard power systems. *Electr. Power Syst. Res.* **2009**, *79*, 550–556.
Hall, D.T. *Practical Marine Electrical Knowladge*, 3rd ed.; Witherby Seamanship: Livingston, UK, 2014.

State-of-the-art of SPS

Notional AC zonal electrical distribution system / IEEE Std 45.3-2015

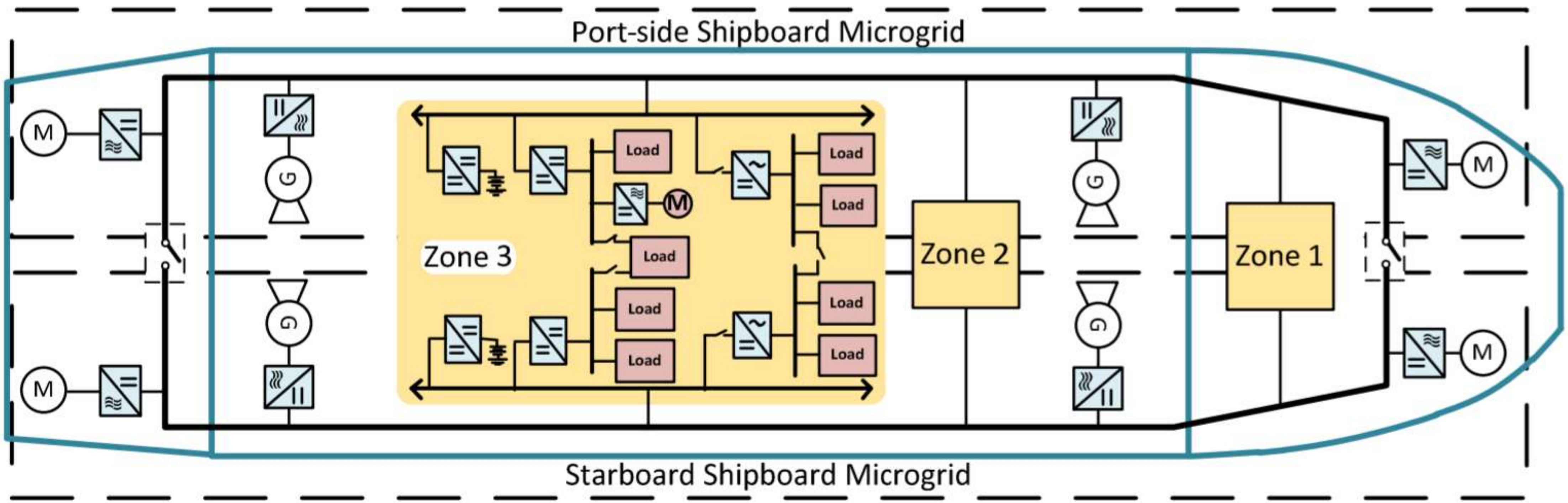


LC – Load Centre, ABT - Automatic Bus Transfer, G – Generator, SWBD - Switchboard

Modern electric ships tend to use zonal electrical distribution system (ZEDS) architecture based IPSs over radial architecture: It is a real **multi-microgrid cluster**

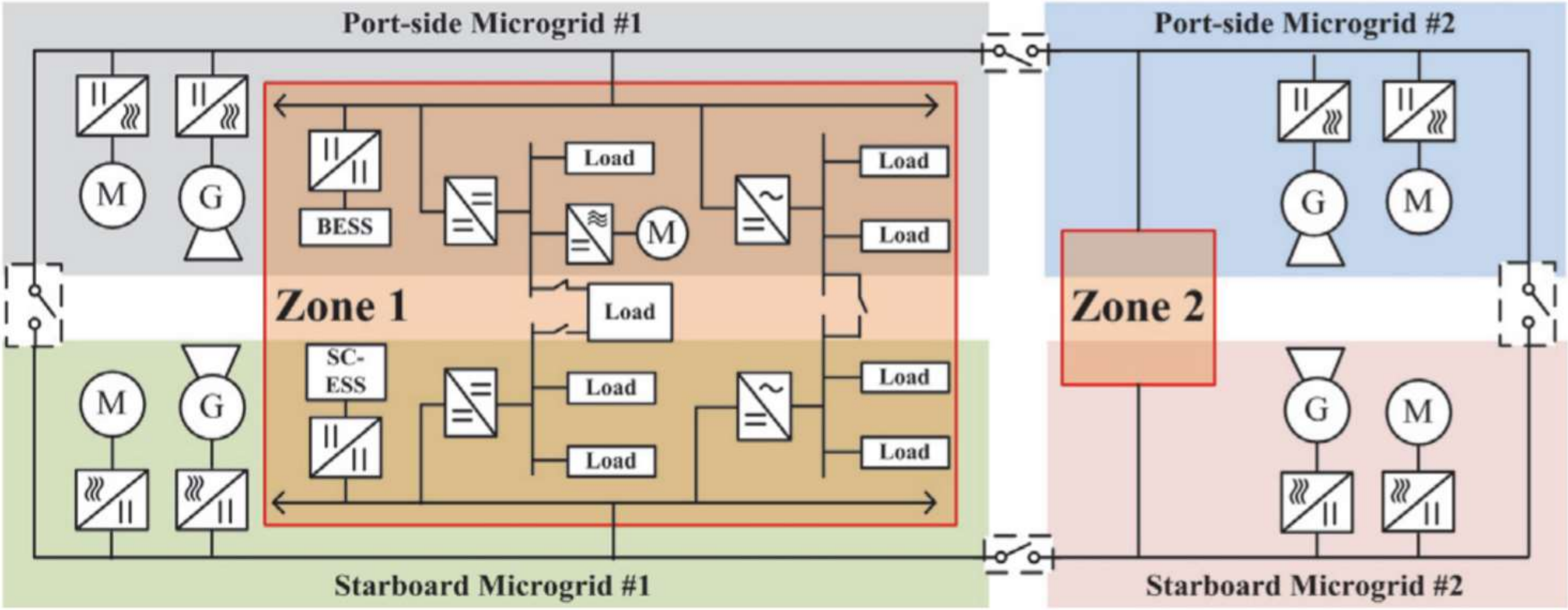
State-of-the-art of SPS

Multi-microgrids electrical propulsion ships



State-of-the-art of SPS

Multi-microgrids electrical propulsion ships

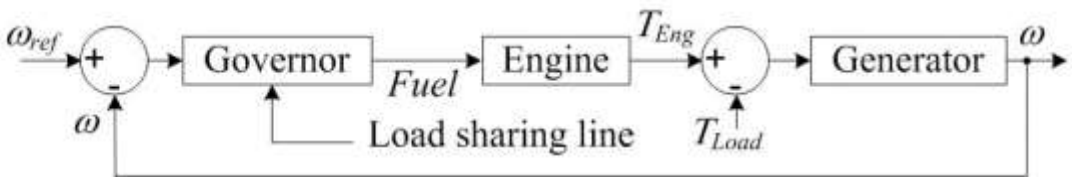


State-of-the-art of SPS

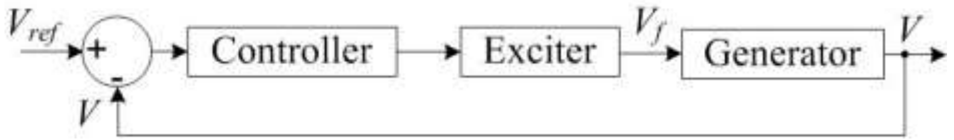
Isochronous Control

- ➢ Measure the power difference between generators and adjust in transient the speed
- ✓ Some companies use CAN bus / ex. Kongsberg
- ✓ No steady-state frequency errors

Isochronous speed controller



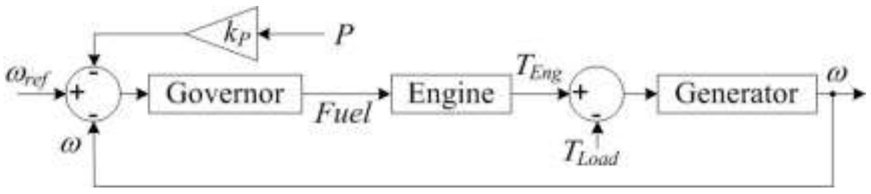
Automatic voltage regulator



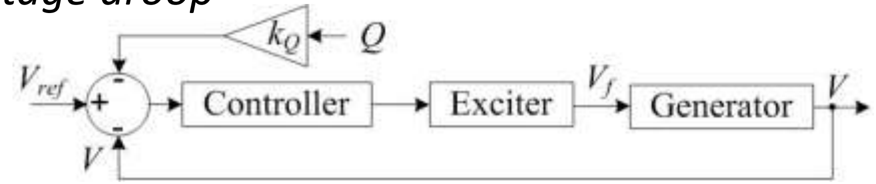
Droop Control

- ➢ Use the inherent droop mechanism of two synchronous generators connected in parallel
- ✓ No intercommunications are needed
- × Large steady-state frequency deviations

Speed droop



Voltage droop

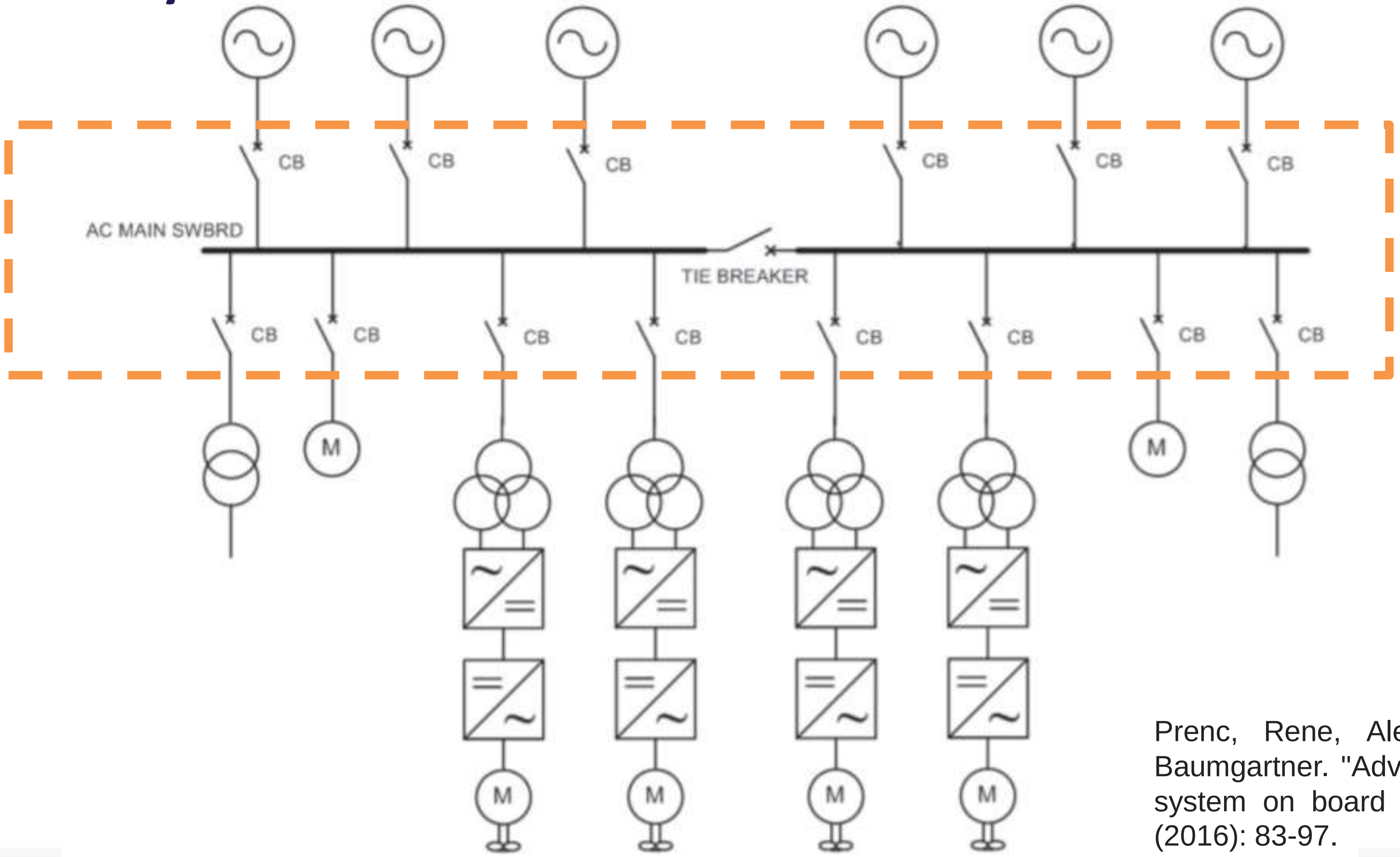


Power Management System / PMS

Functions:

- **Energy saving:**
  - reduction in specific fuel oil consumption (SFOC)
  - reduction in propulsion fuel consumption
  - reduction in overall vessel fuel consumption.
- **Automatic start/stop/standby of auxiliary generators**
- **Automatic load sharing**
- **Load shedding**
- **Automatic synchronizing and system restoration**
- **Monitoring and load analysis illustration**
- **Load transfer:** can control and monitor the load transfer from shaft to auxiliary and vice versa in hybrid electric ships, and shore power to auxiliary in cold ironing.

AC Shipboard Power System

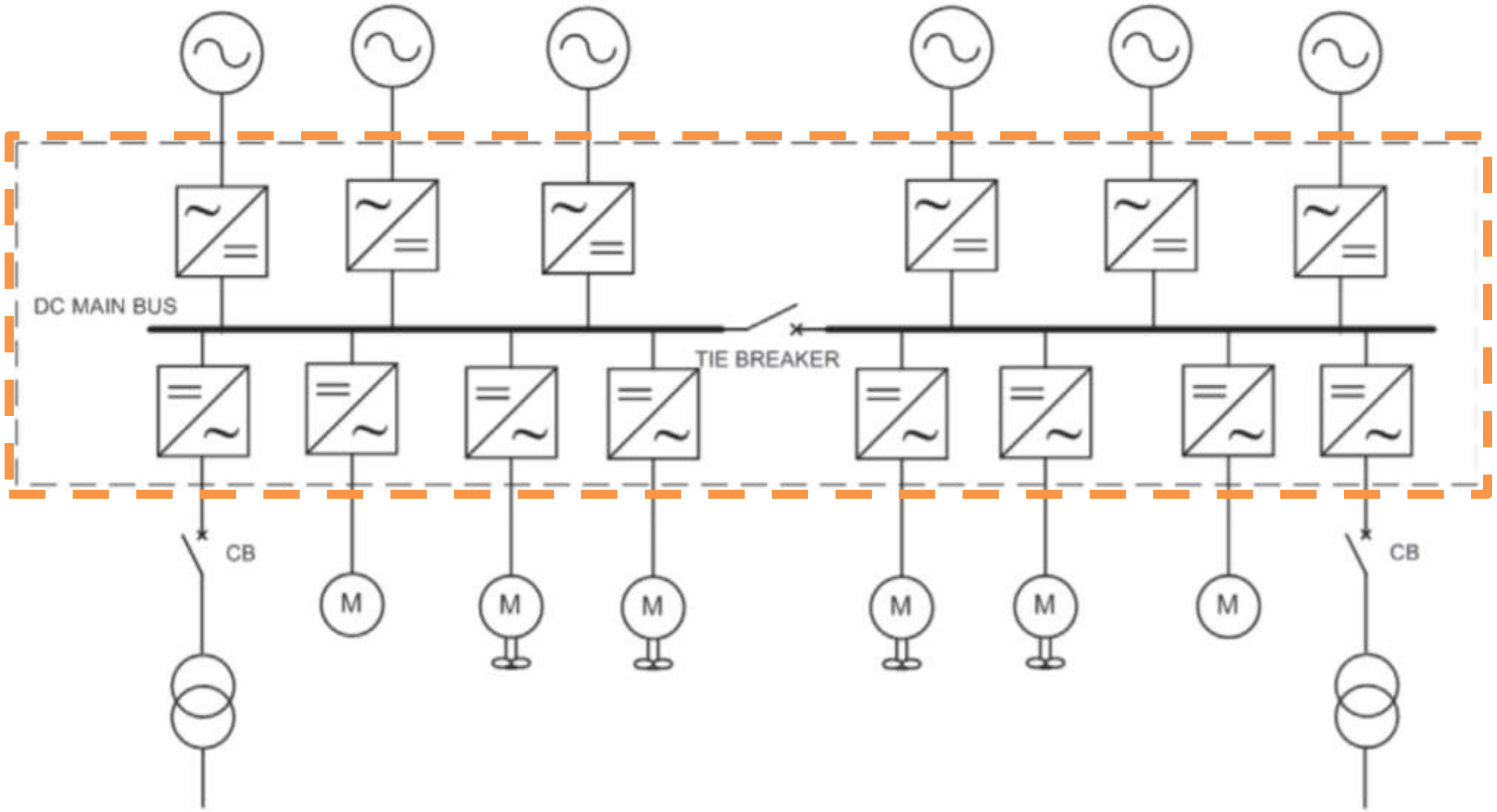


AC Main Switchboard

Prenc, Rene, Aleksandar Cuculić, and Ivan Baumgartner. "Advantages of using a DC power system on board ship." *Pomorski zbornik* 52.1 (2016): 83-97.

State-of-the-art of SPS

Onboard DC grid – Multidrive power system scheme

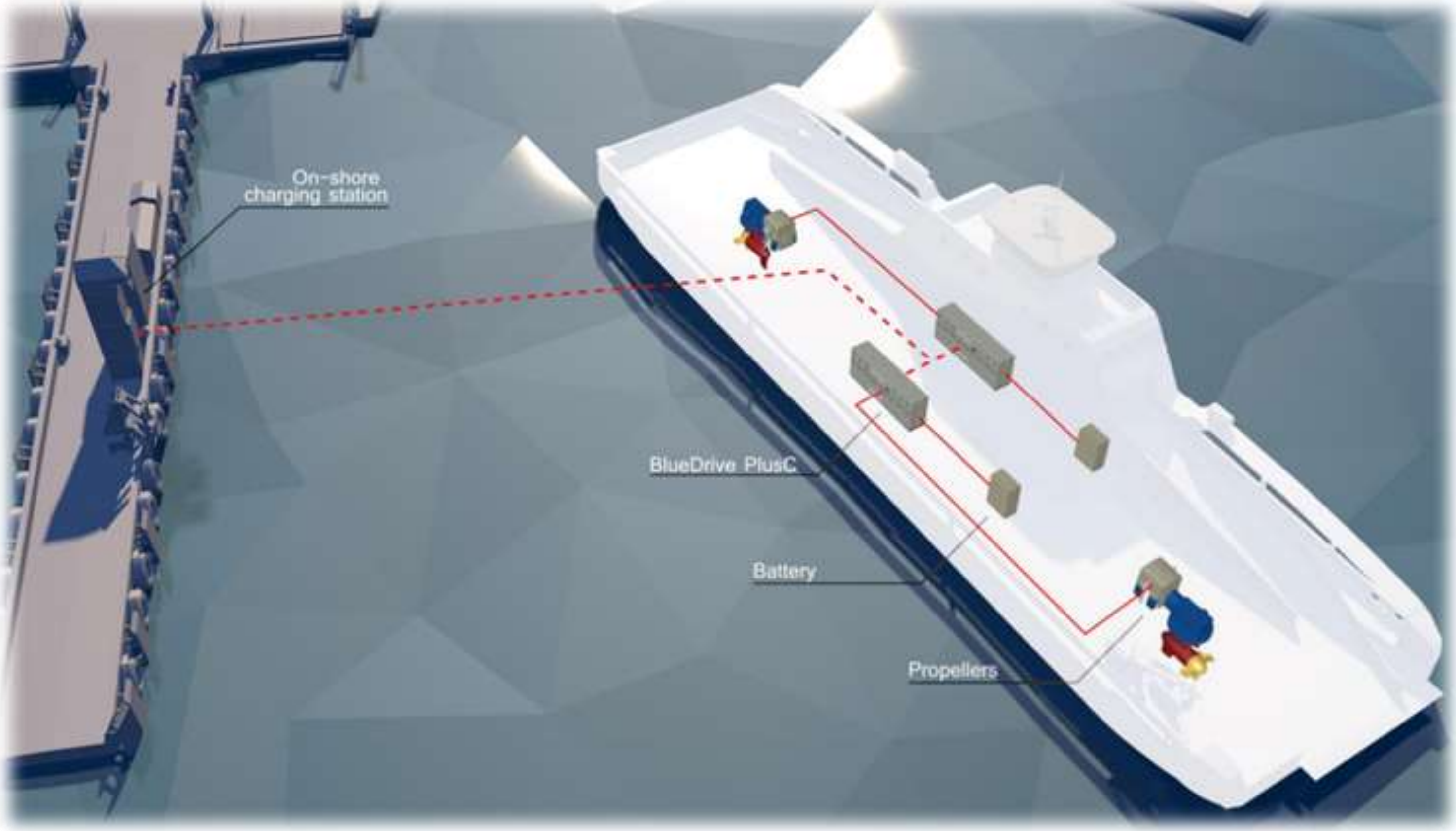


BlueDrive PlusC from SIEMENS

<20MW

State-of-the-art of SPS

Onboard DC grid – Multidrive power system scheme



Source: SIEMENS

Onboard DC grid – Distributed power system scheme

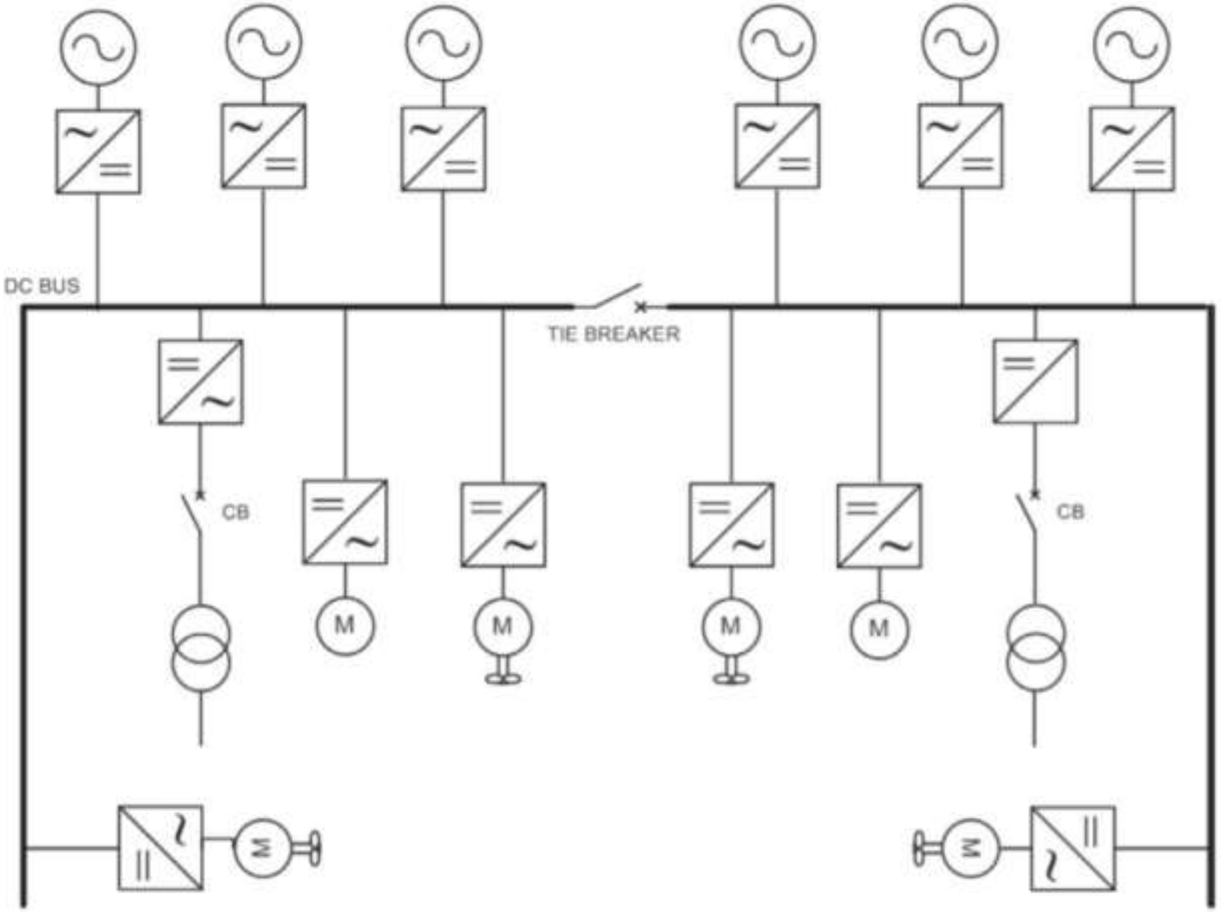


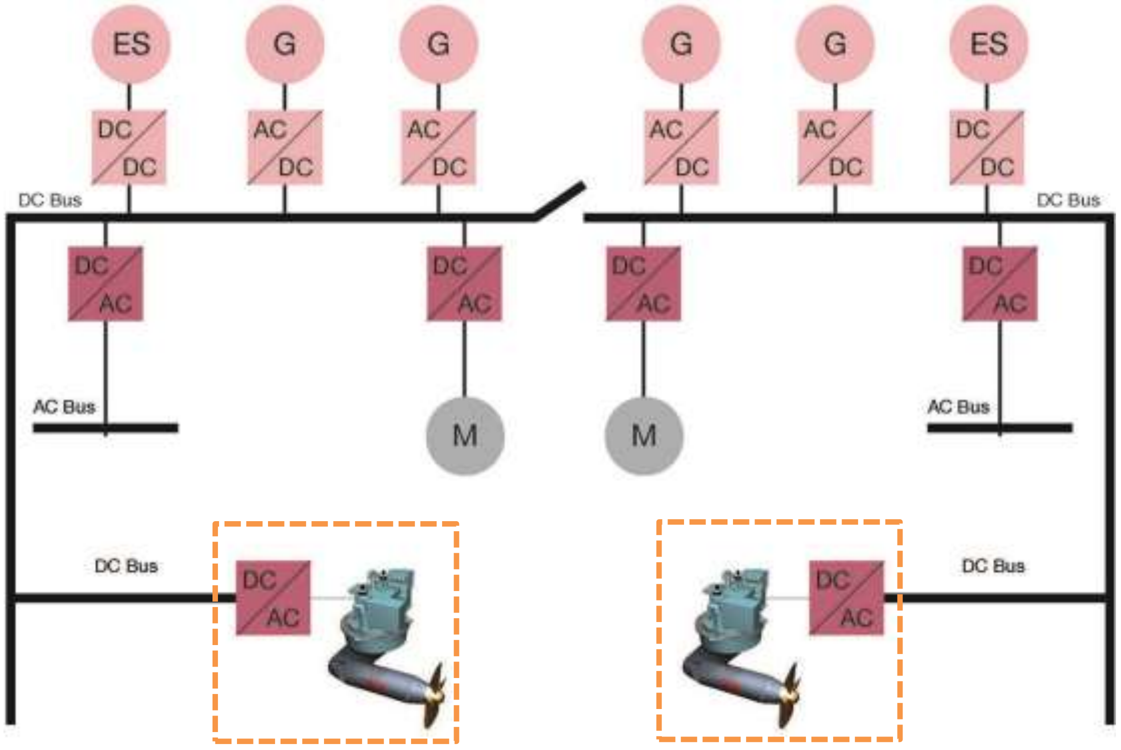
ABB Concept

State-of-the-art of SPS

Onboard DC Grid

Vessel layout example – Onboard DC Grid

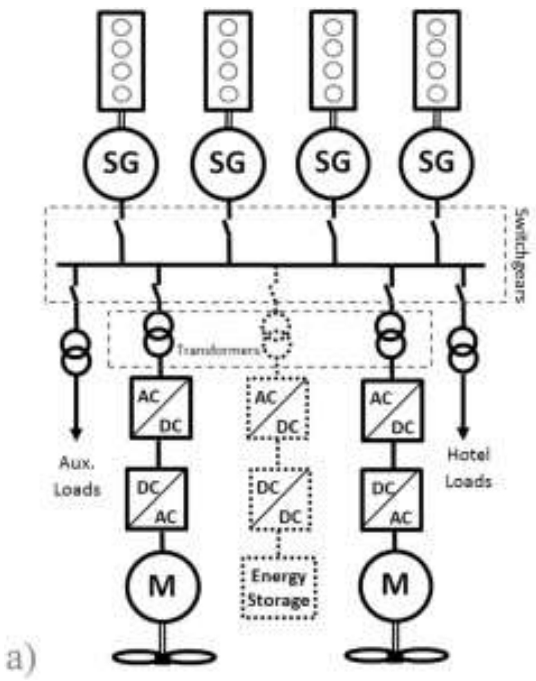
<20MW



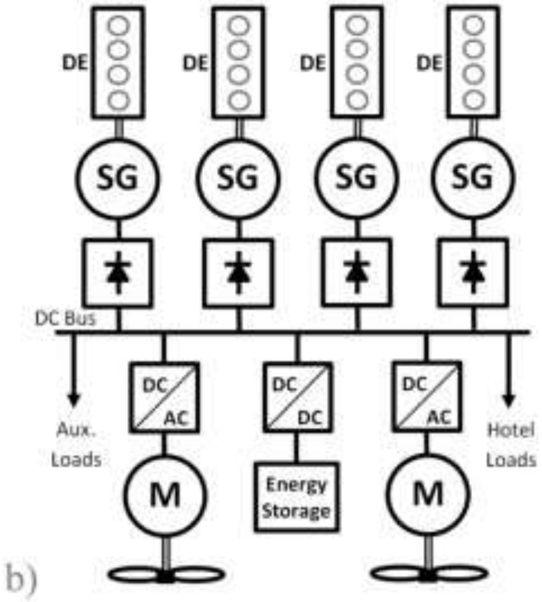
Source: ABB

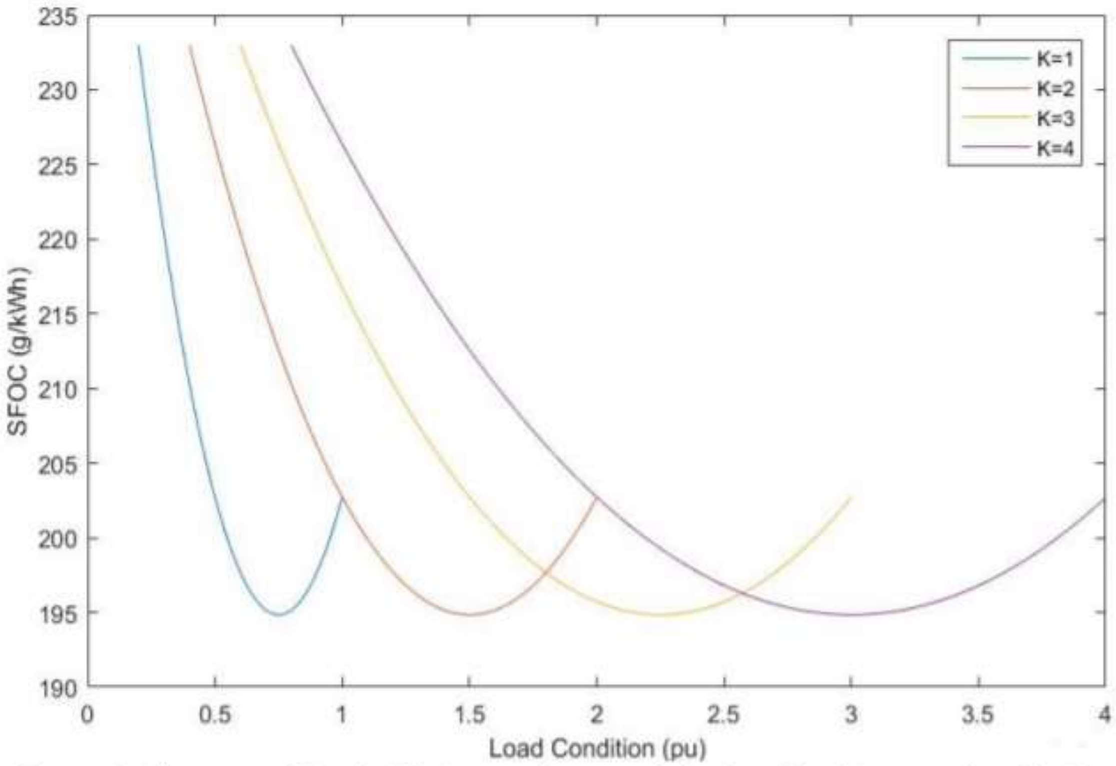
State-of-the-art of SPS

AC SMG



DC SMG

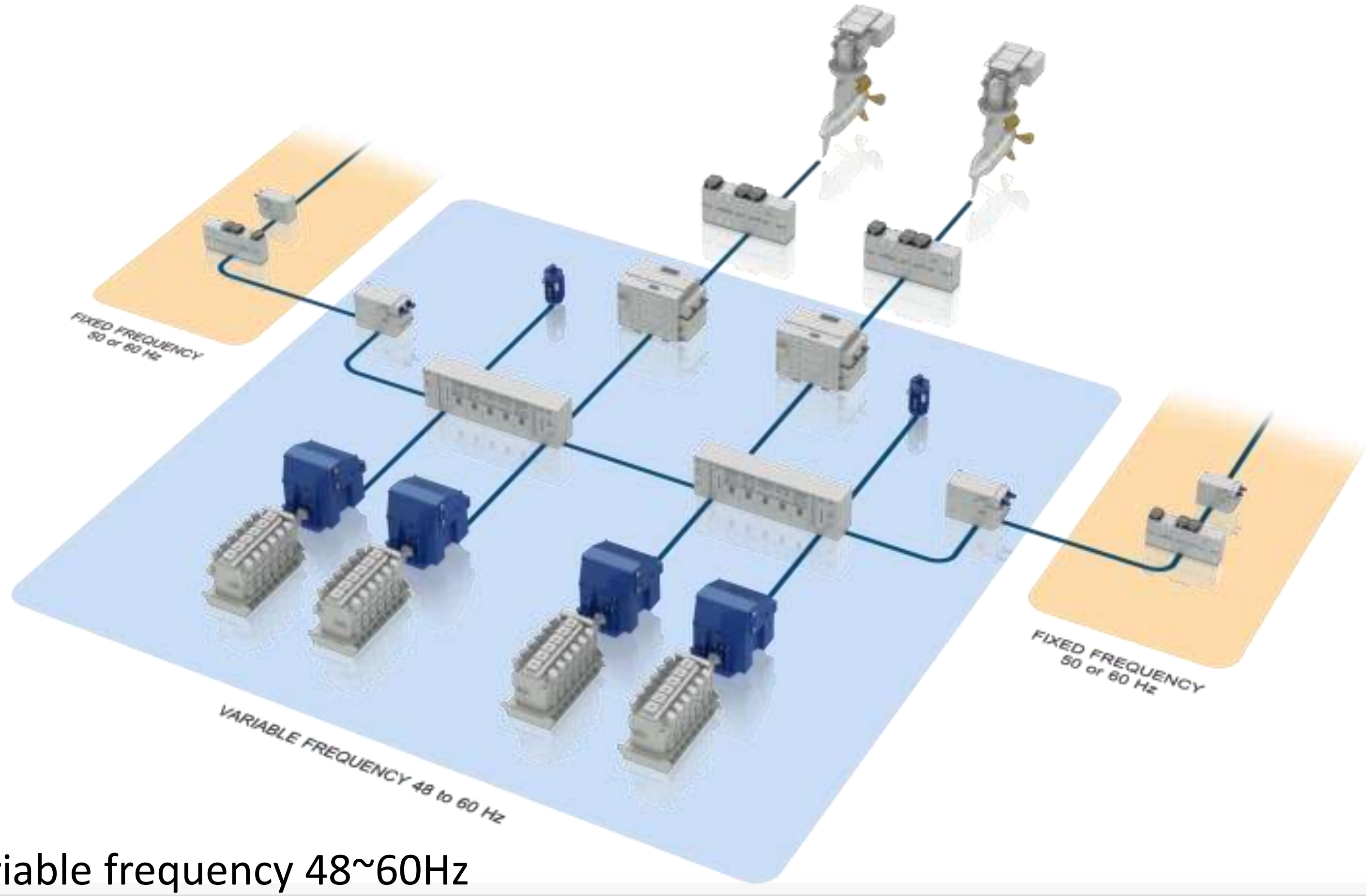


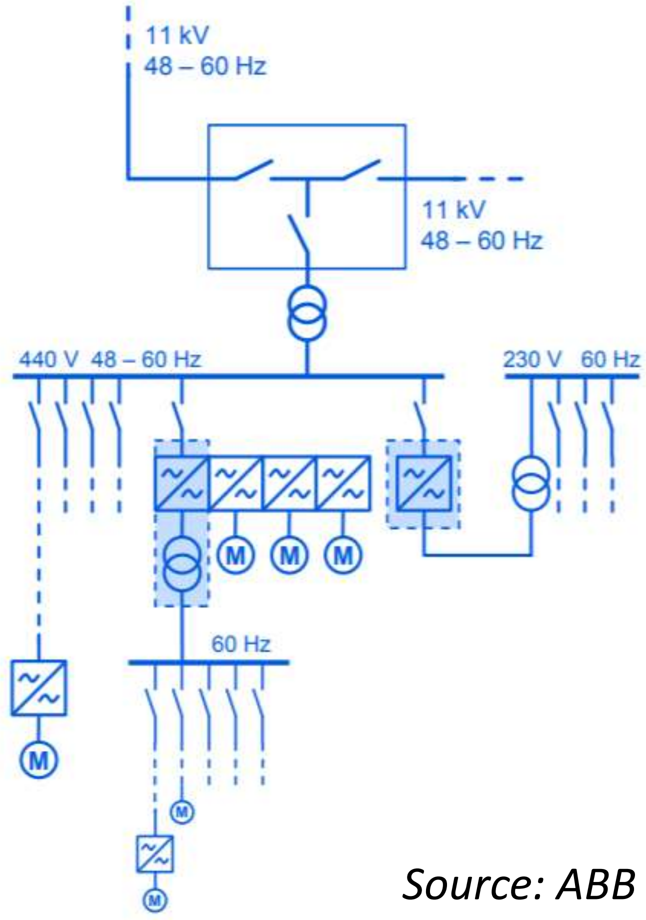


Schematic diagram of fuel efficiency characteristic for diesel generation (in fixed speed)

State-of-the-art of SPS

Dynamic AC concept – DAC by ABB

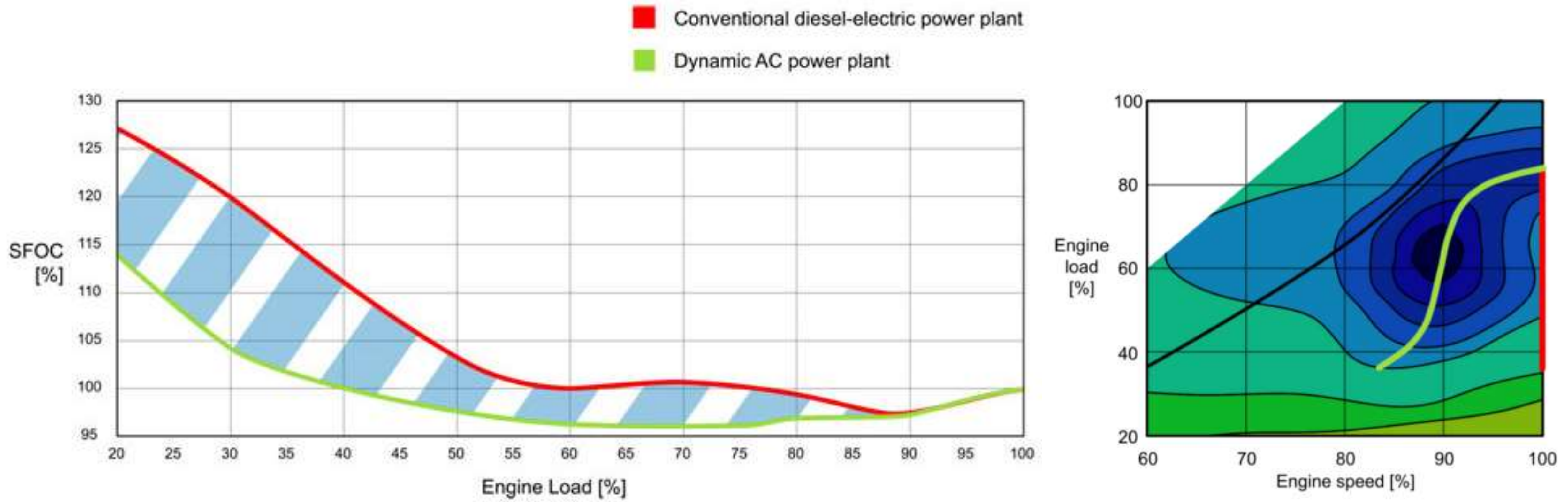




Source: ABB

Variable frequency 48~60Hz

Dynamic AC concept – DAC by ABB

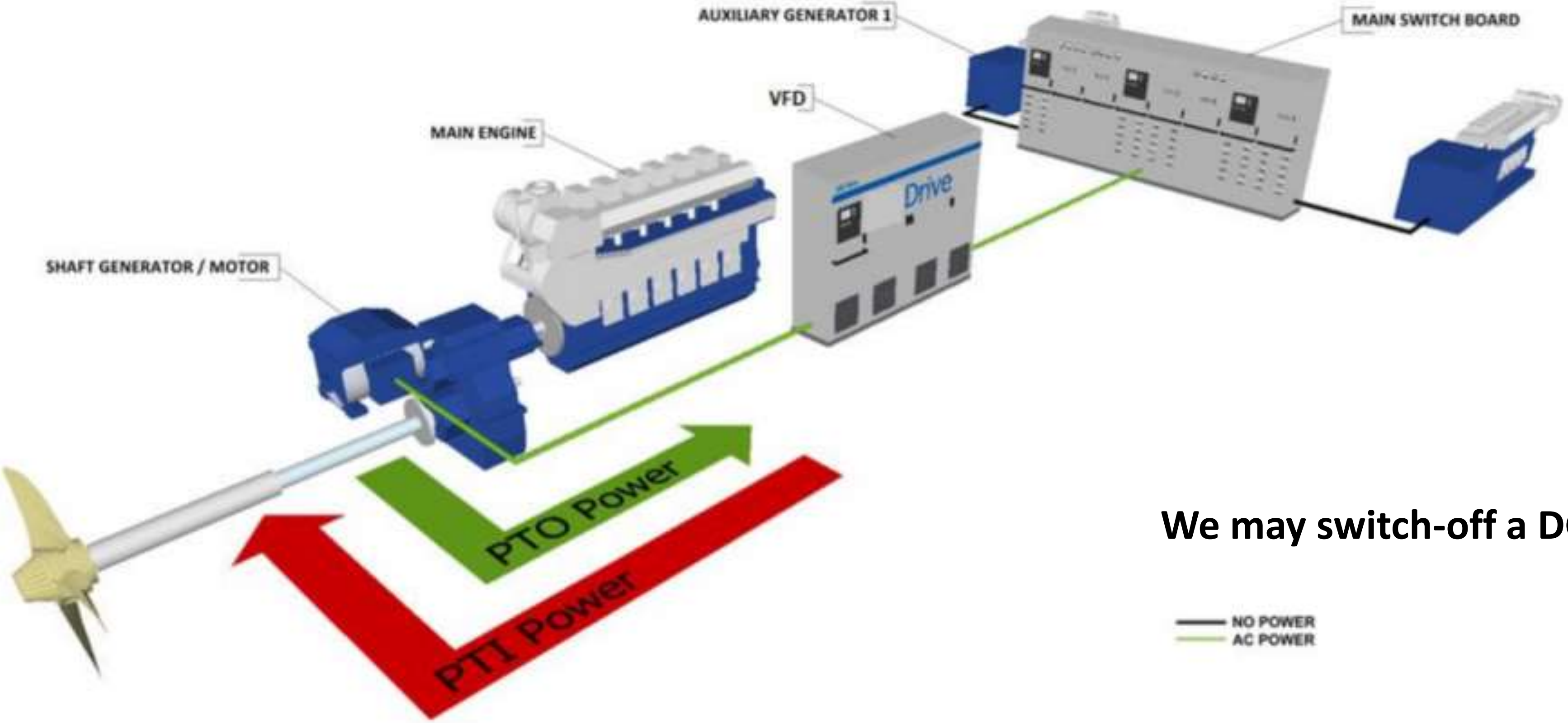


Benefits of Dynamic AC- Up to 6 % annual fuel savings for large cruise vessel (+20MW)

Source: ABB

State-of-the-art of SPS

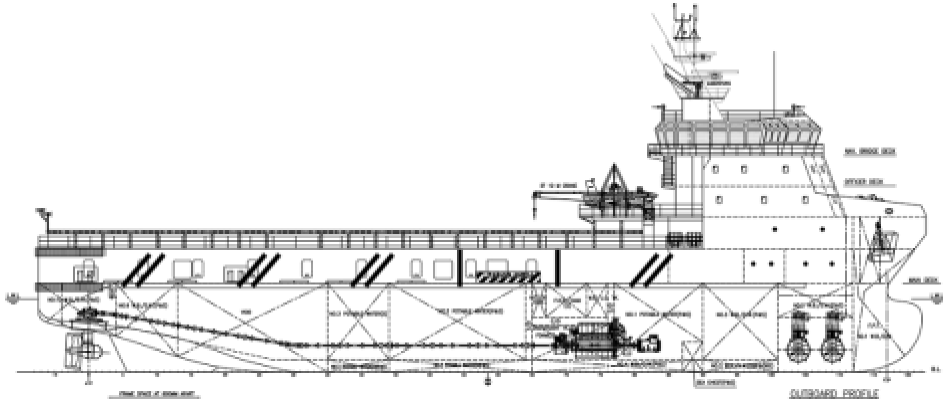
Operating modes (PTO/PTI) of a shaft generator/motor system with VFD-



We may switch-off a DG!

State-of-the-art of SPS

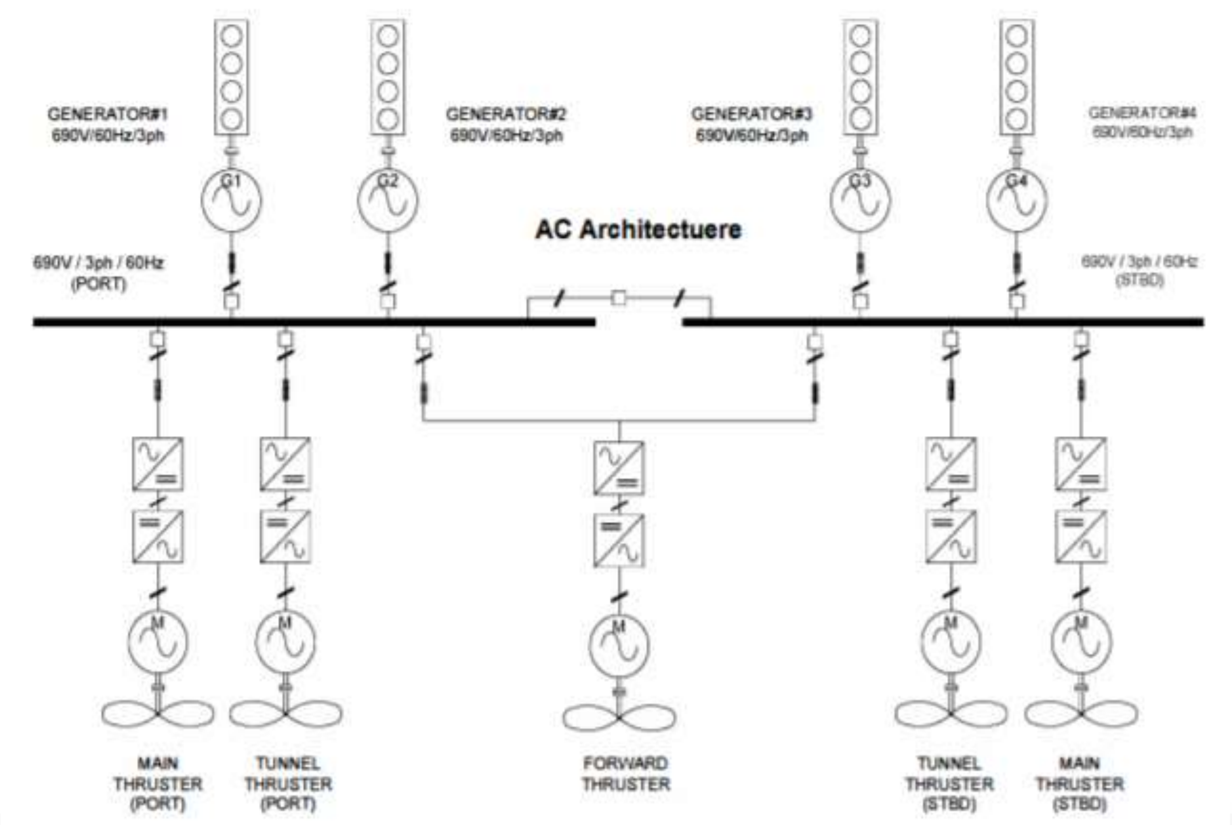
Platform support vessel (PSV)

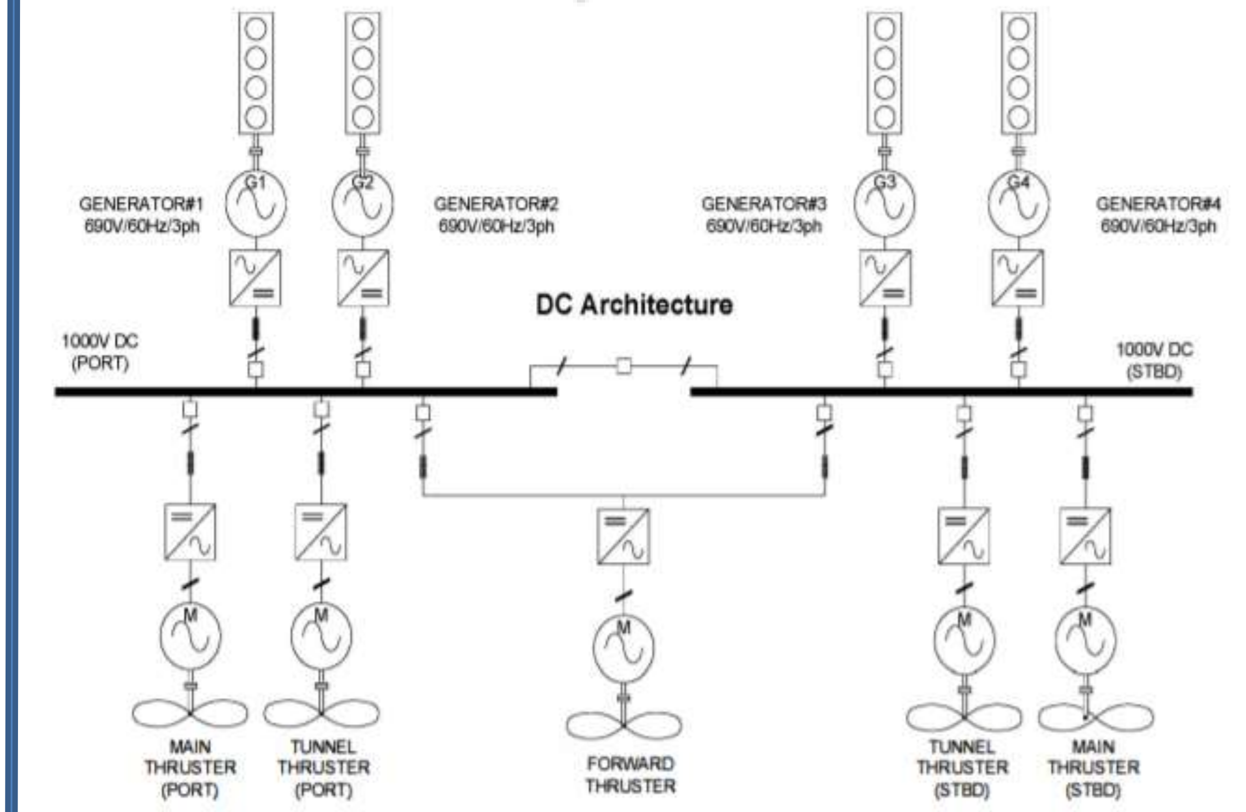


State-of-the-art of SPS

Platform support vessel (PSV)

AC → DC

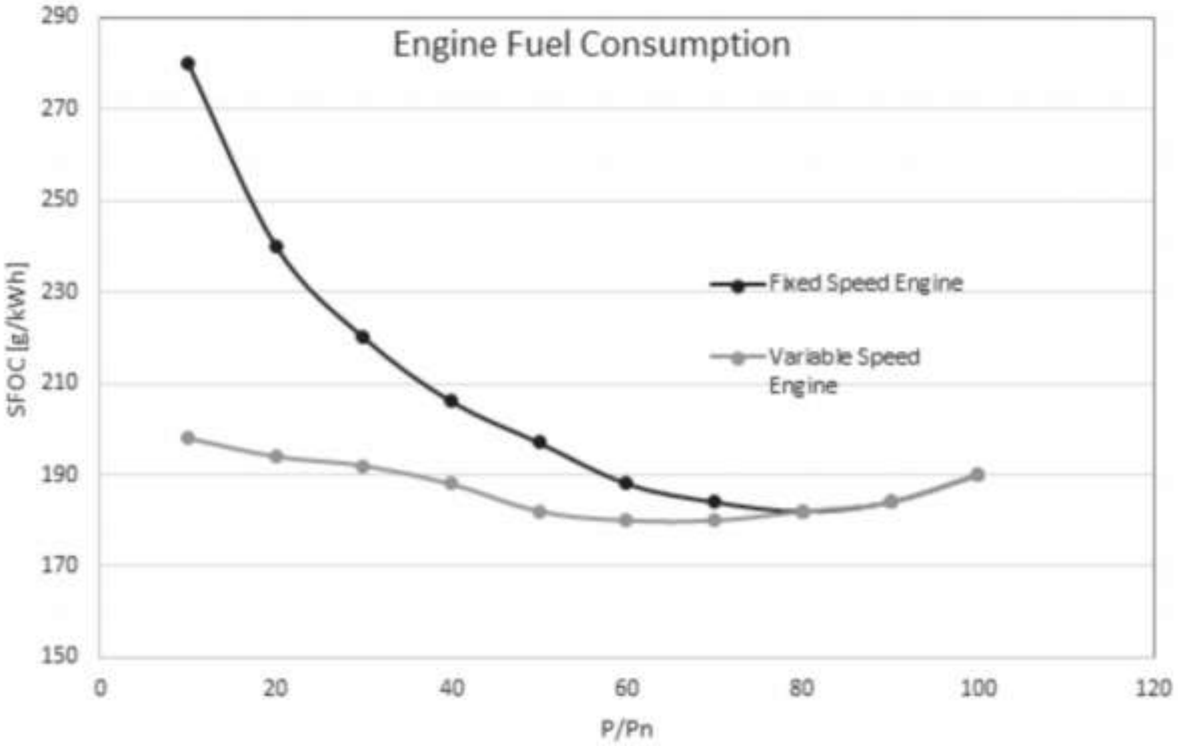




State-of-the-art of SPS

Benefits of using a DC ship power system

- Improvement of prime mover efficiency and reduction of fuel costs,
- Weight and space savings,
- Generators operating with a unity power factor,
- Lower transmission losses,
- Faster and simpler parallel connection of generators,
- Simpler implementation of energy storage.



Rao, Srinivasa, et al. "An exercise to qualify LVAC and LVDC power system architectures for a Platform Supply Vessel." Transportation Electrification Asia-Pacific (ITEC Asia-Pacific), 2016 IEEE Conference and Expo. IEEE, 2016.

Offshore Supply Vessel: Viking Lady

- Norway
- 2.2m long x 21m wide
- Gross tonnage 6,100t
- Dead weight 5,900t
- 25 people

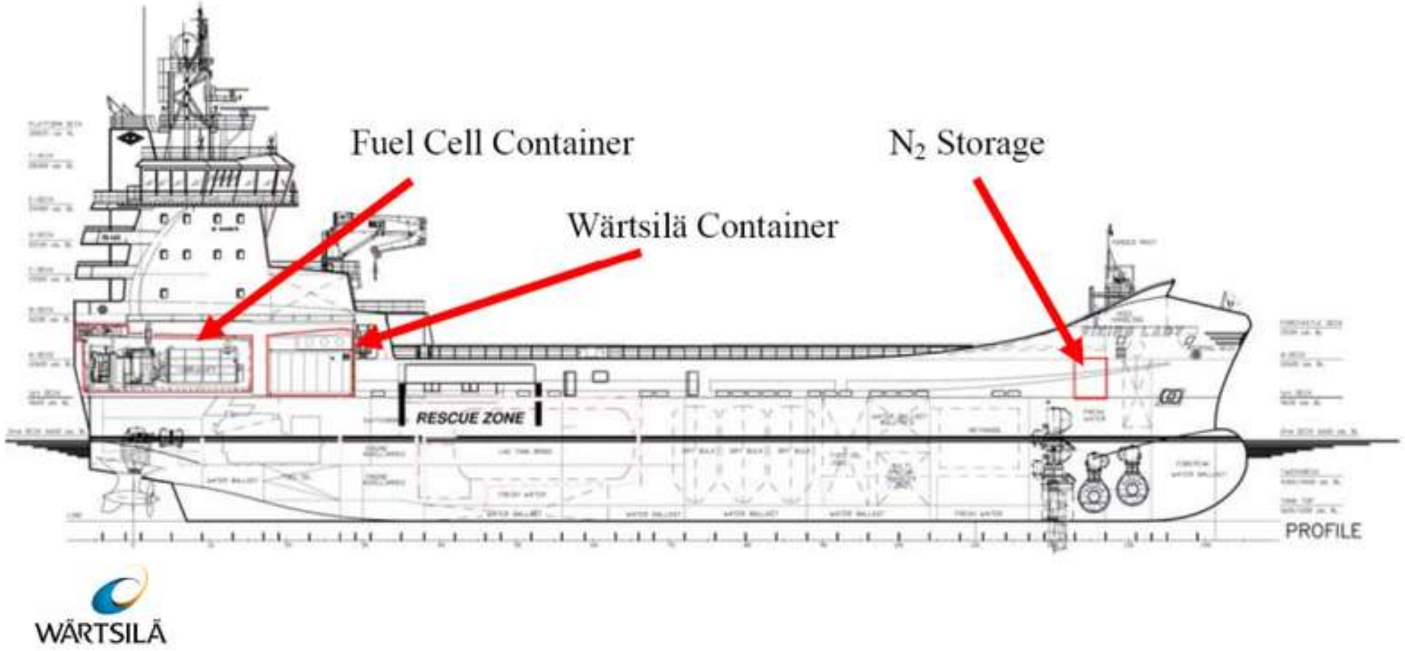
- deck area 945m²
- deck load of 3,450t
- water ballast capacity of 3,518m³
- Capacity 993m³ of fresh water
- 167m³ of methanol.

- Kongsberg K-Pos 2 dynamic positioning (DP) system.
- 4 x 2,010kW Wartsila 6R32DF engines
- 4 x 1,950kW main generators Alconza NIR 6391 A-10LWs, each producing of power.
- 2 x Rolls Royce AZP 100FP propeller systems

Source: Wartsila

Offshore Supply Vessel: Viking Lady

System integration

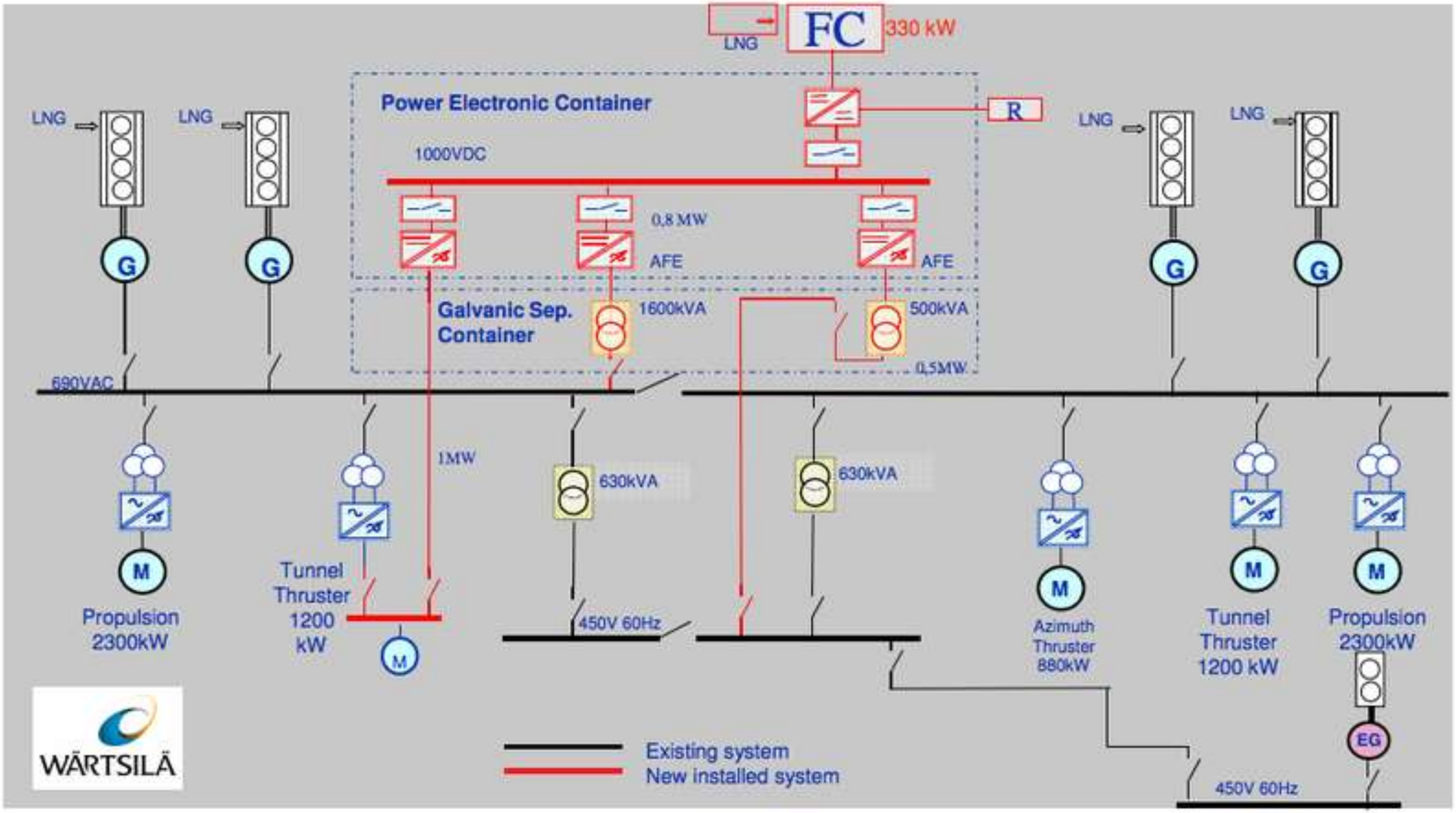


Source: Wartsila

Viking Lady

Fuel cell integration in the electric propulsion system

- Dual-fuel liquefied natural gas (LNG)/diesel-electric power plant
- Fuel cell operates at 650°C and generates 320kW



Source: Wartsila

Viking Lady

Due to the combined use of the fuel cell and a gas engine, vessel can reduce: sulphur oxide by 100%, nitrogen oxide by 85% and carbon dioxide by 20%.

Source: Wartsila

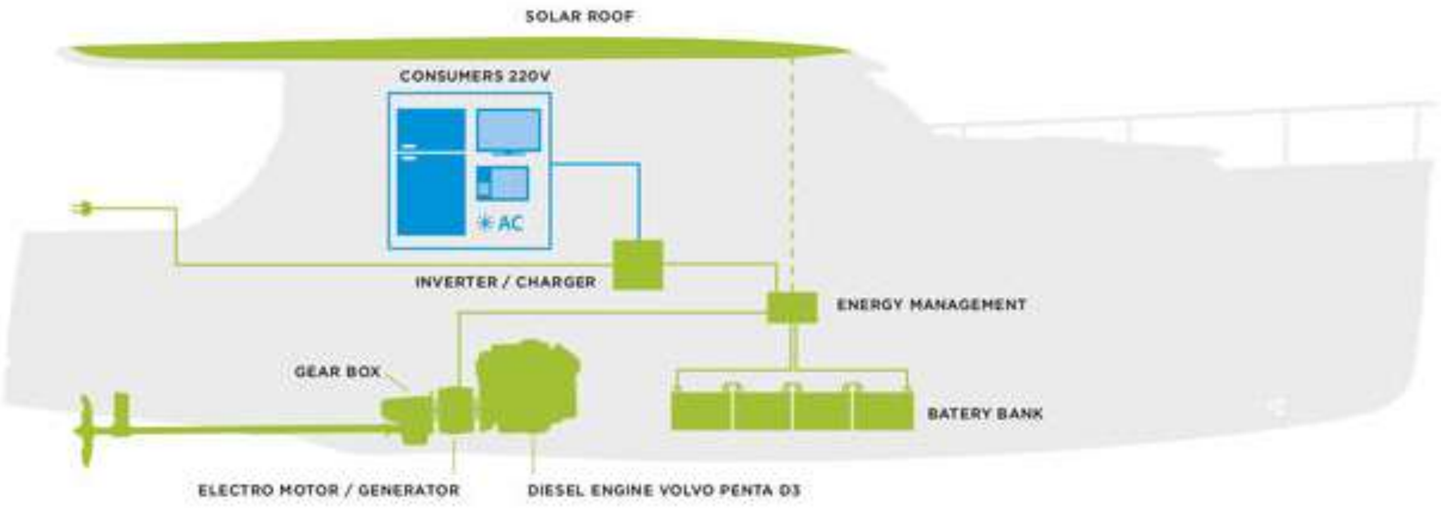
Hybrid Yatchs

GREENLINE YACHTS

Lithium battery technology available: a 11,5 kWh on Greenline 33, 23 kWh on Greenline 40 and 46 kWh on Greenline 46 (battery pack with a permissible discharge of 100%).

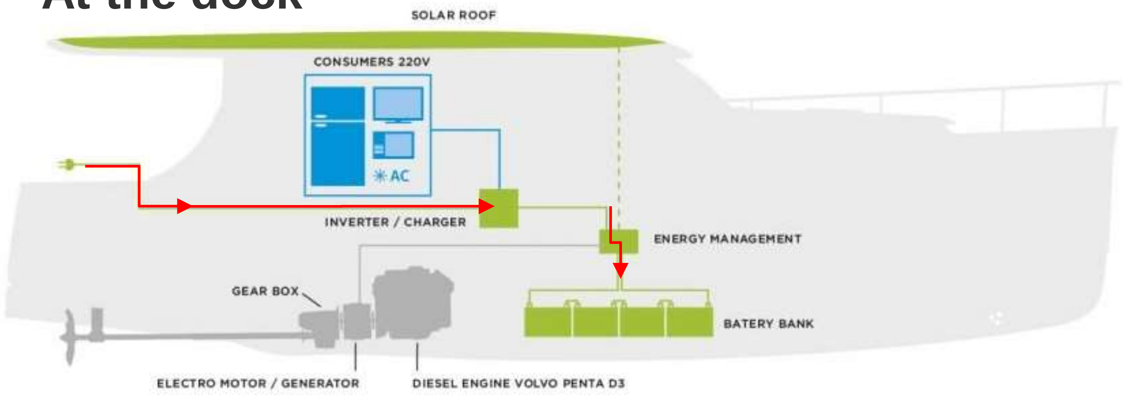
www.greenlinehybrid.si

Hybrid Yatchs

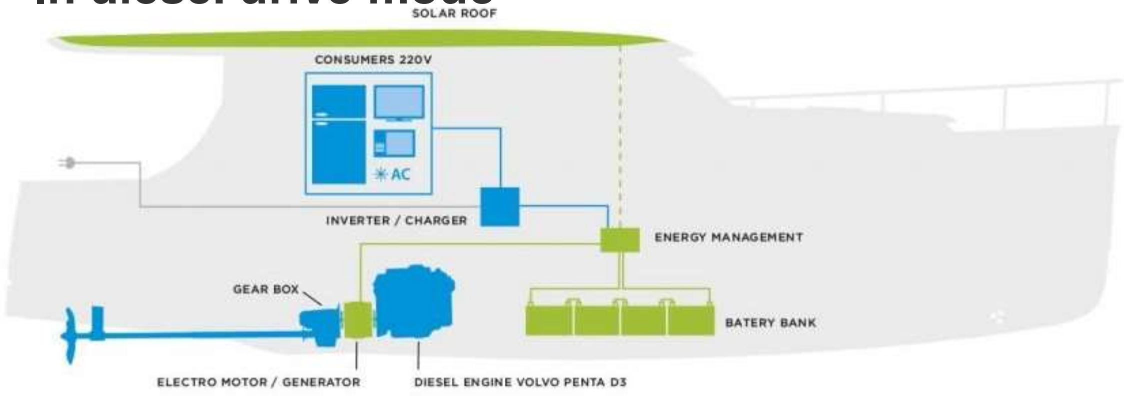


Hybrid Yatchs: Operation Modes

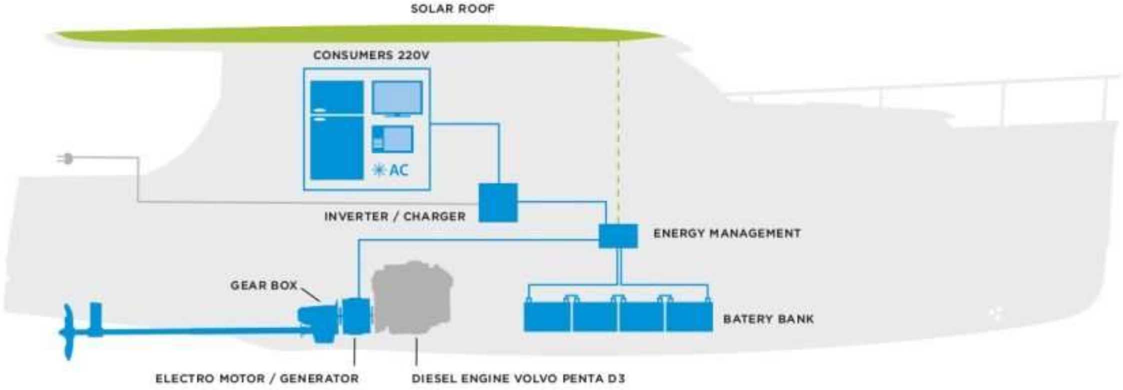
At the dock



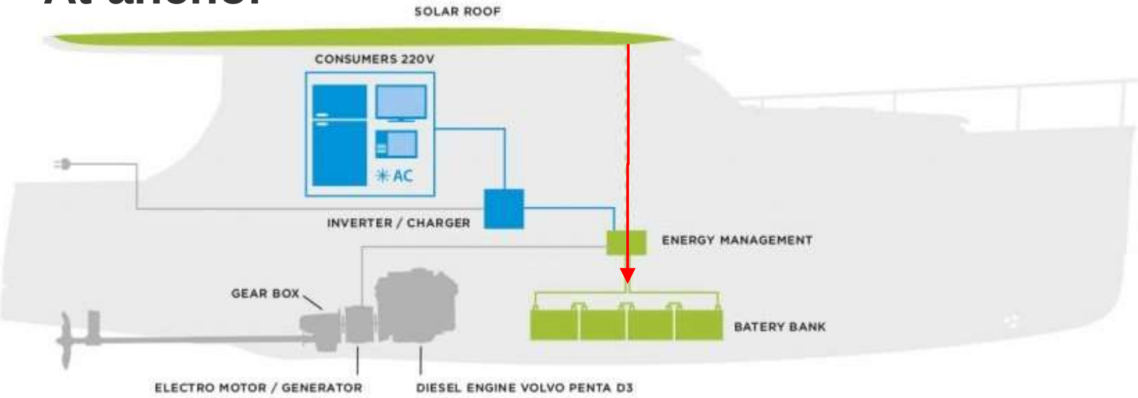
In diesel drive mode



In electric drive mode



At anchor



Hybrid Ferries

Hybrid Ferries

Hybrid Ferries

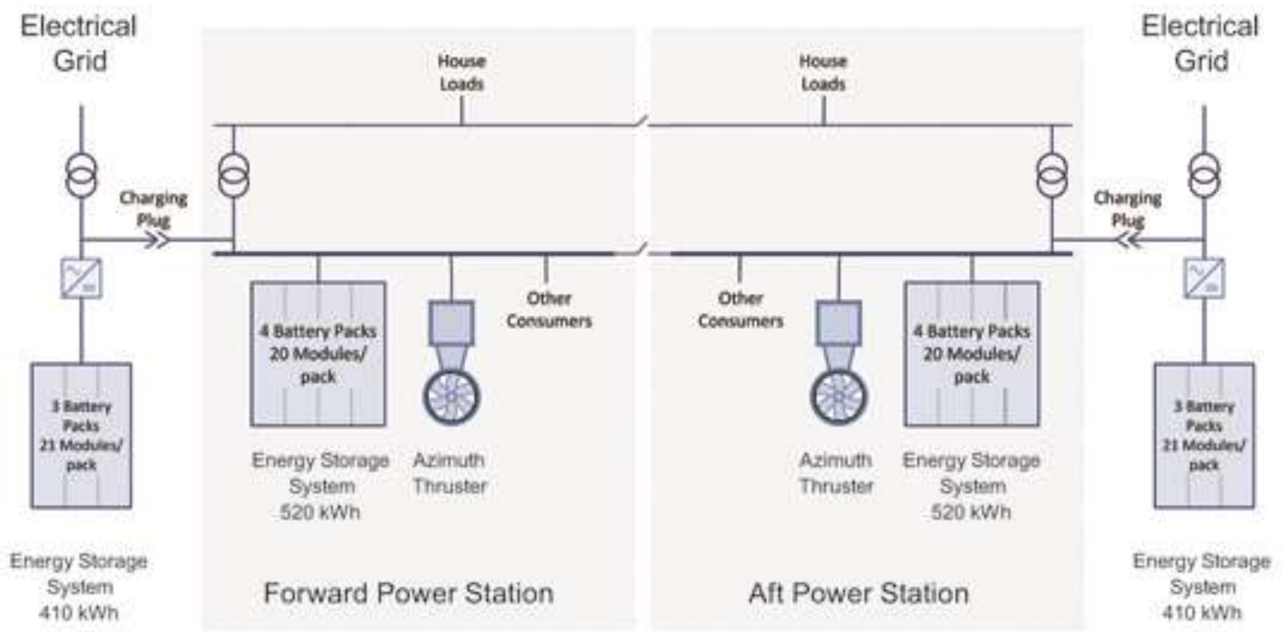
Source: Scandlines

Ampere Ferry from Norled (Norway)

Norled AS, MF Ampere Ferry powered by Corvus Energy ESSs on both vessel and shore charging stations.

Source: Norled

World's First All-electric Car Ferry



- Designed by Siemens AS and Corvus Energy
- Onshore Corvus Energy 410kWh
- ESS comprised of 63 AT6500 Liquid-Cooled modules installed on both sides of the route, each providing near instantaneous transfer of power to the vessel ESS.

Source: Norled

Outline

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- Cold-Ironing

Outline

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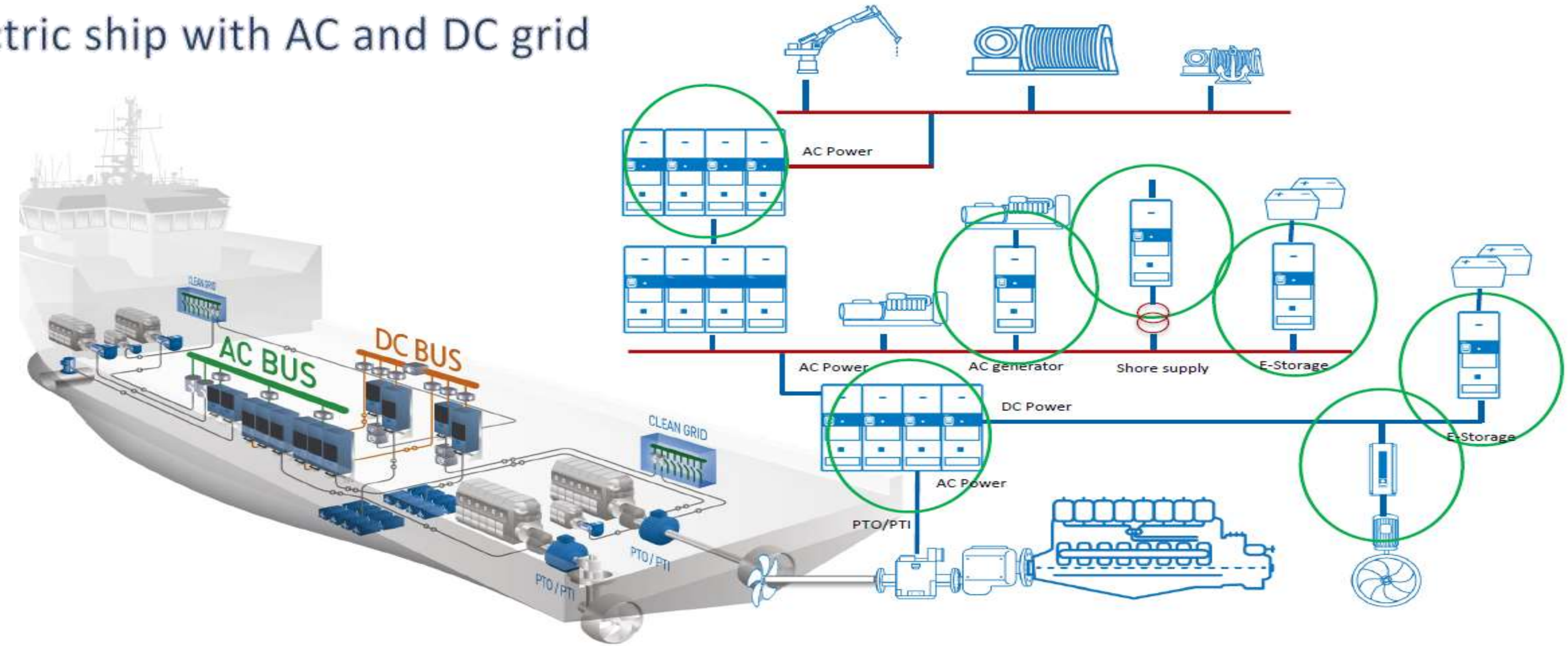
State-of-the-art of SPS

Fully electric ship with AC and DC grid



Source: Vacon Power / Danfoss

HyELEF project 2017

Hybrid Electrical Ferry including Batteries

AALBORG UNIVERSITY
DENMARK

VISEDO
Electricity in Motion.

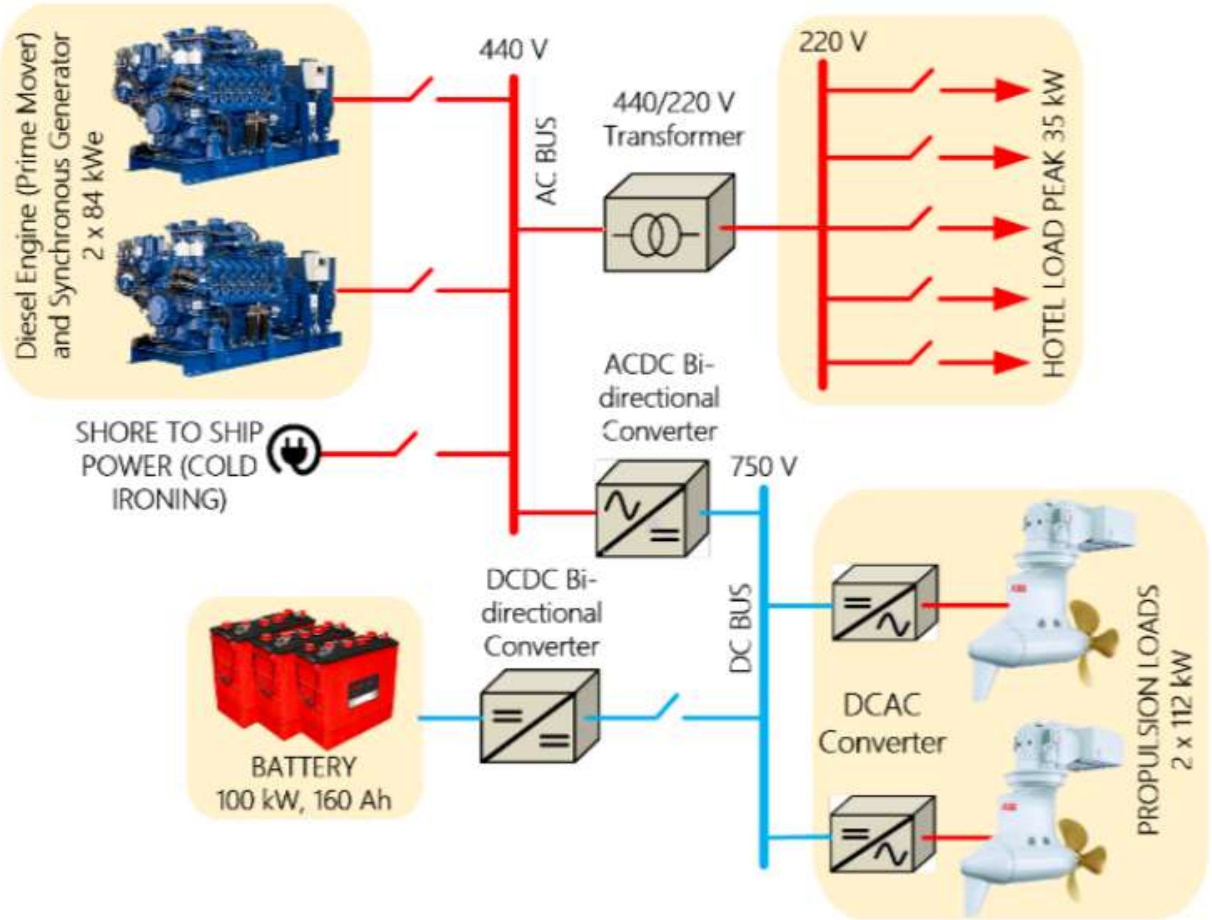
財團法人 船舶暨海洋產業研發中心
Ship and Ocean Industries R&D Center

Asia's First Hybrid Electric Ferry

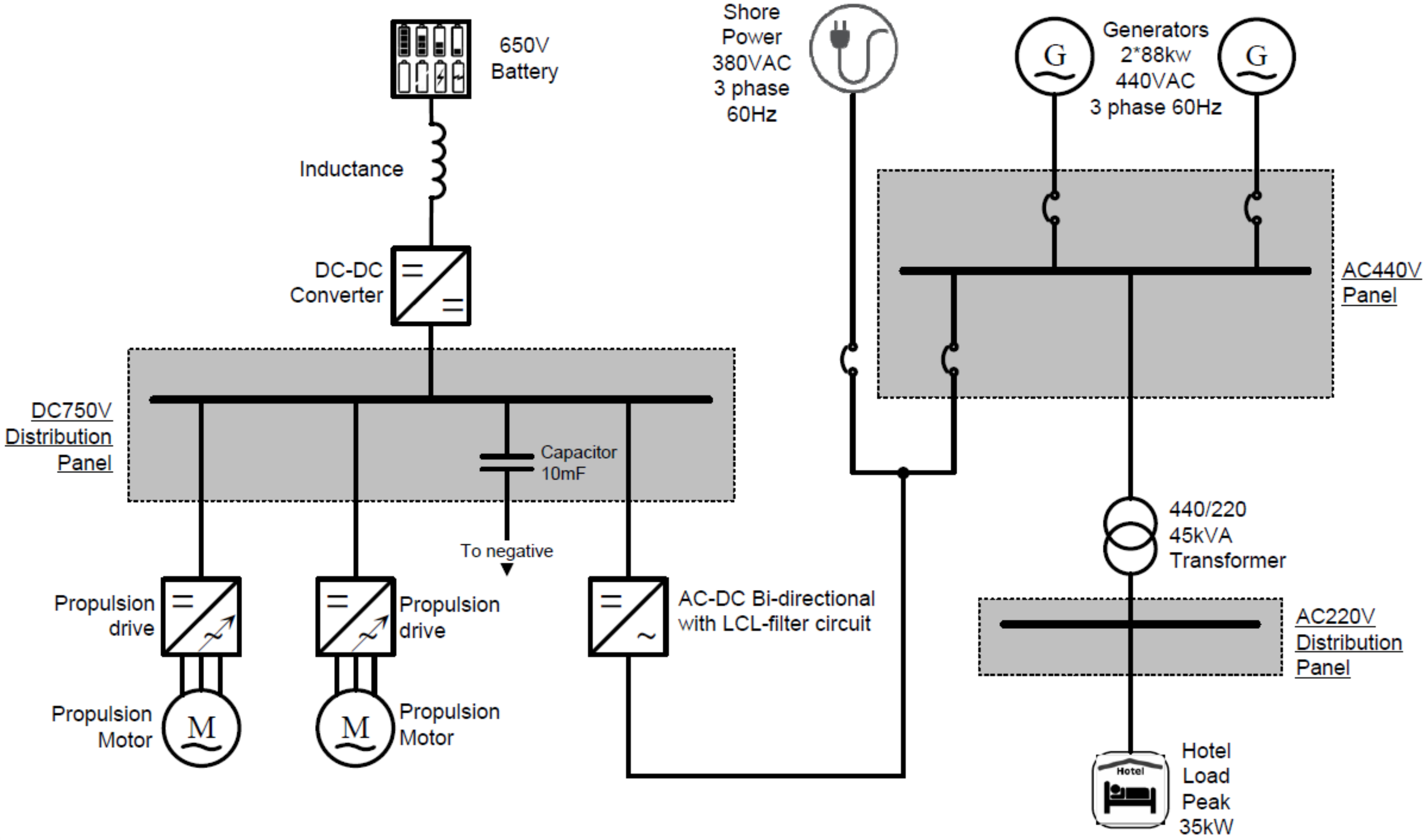
Ferry in Kaohsiung

Ferry retrofitting

Asia's First Hybrid Electric Ferry



Asia's First Hybrid Electric Ferry



Asia's First Hybrid Electric Ferry

- Original gear box, main shaft, and propeller.
- Original throttle system.
- Same driving characteristic.
- Low cost.

Source: SOIC

Asia's First Hybrid Electric Ferry

- Reconstruct storage room.
- Away from genset heat zone.
- Easy access for maintenance.

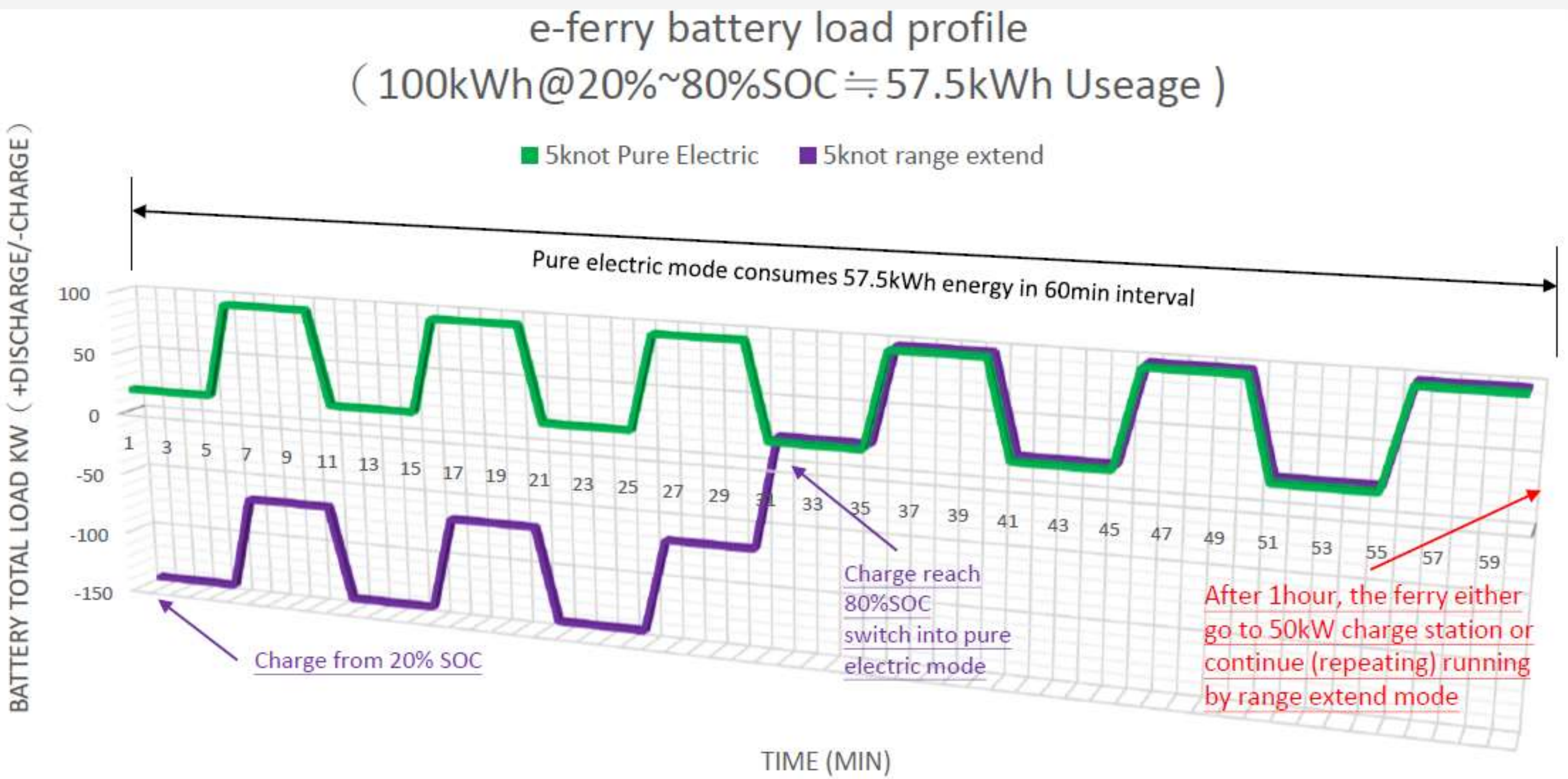
Source: SOIC

Asia’s First Hybrid Electric Ferry

- DC/DC, DC/AC, LCL, Inductor.
- Extreme compact size.
- Very low heat generate.

Source: SOIC

Asia's First Hybrid Electric Ferry

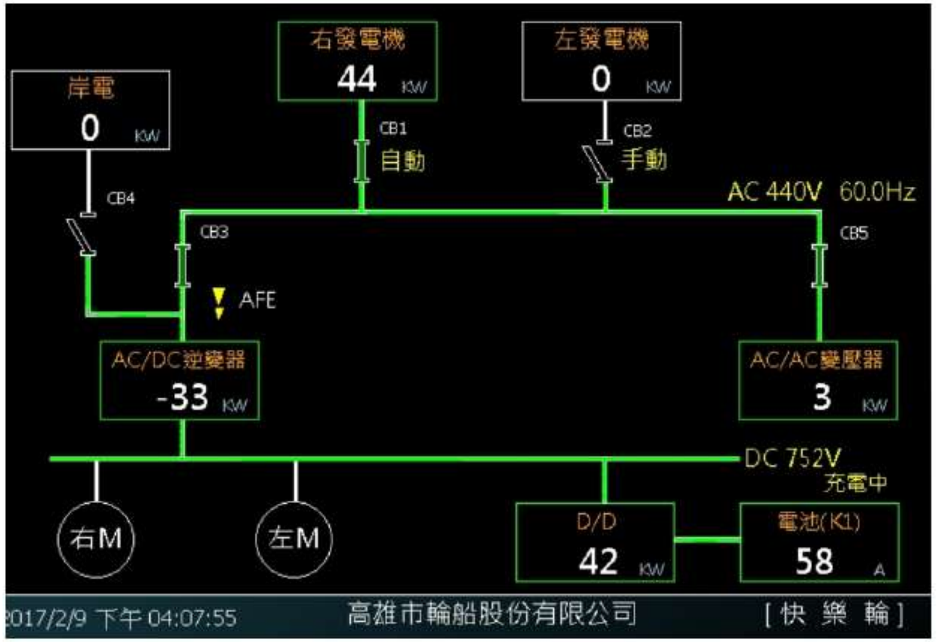


- Every one hour running, the boat can either continue by range extend or stop and doing shore 50kW one hour charging.

Source: SOIC

Asia's First Hybrid Electric Ferry

PMS



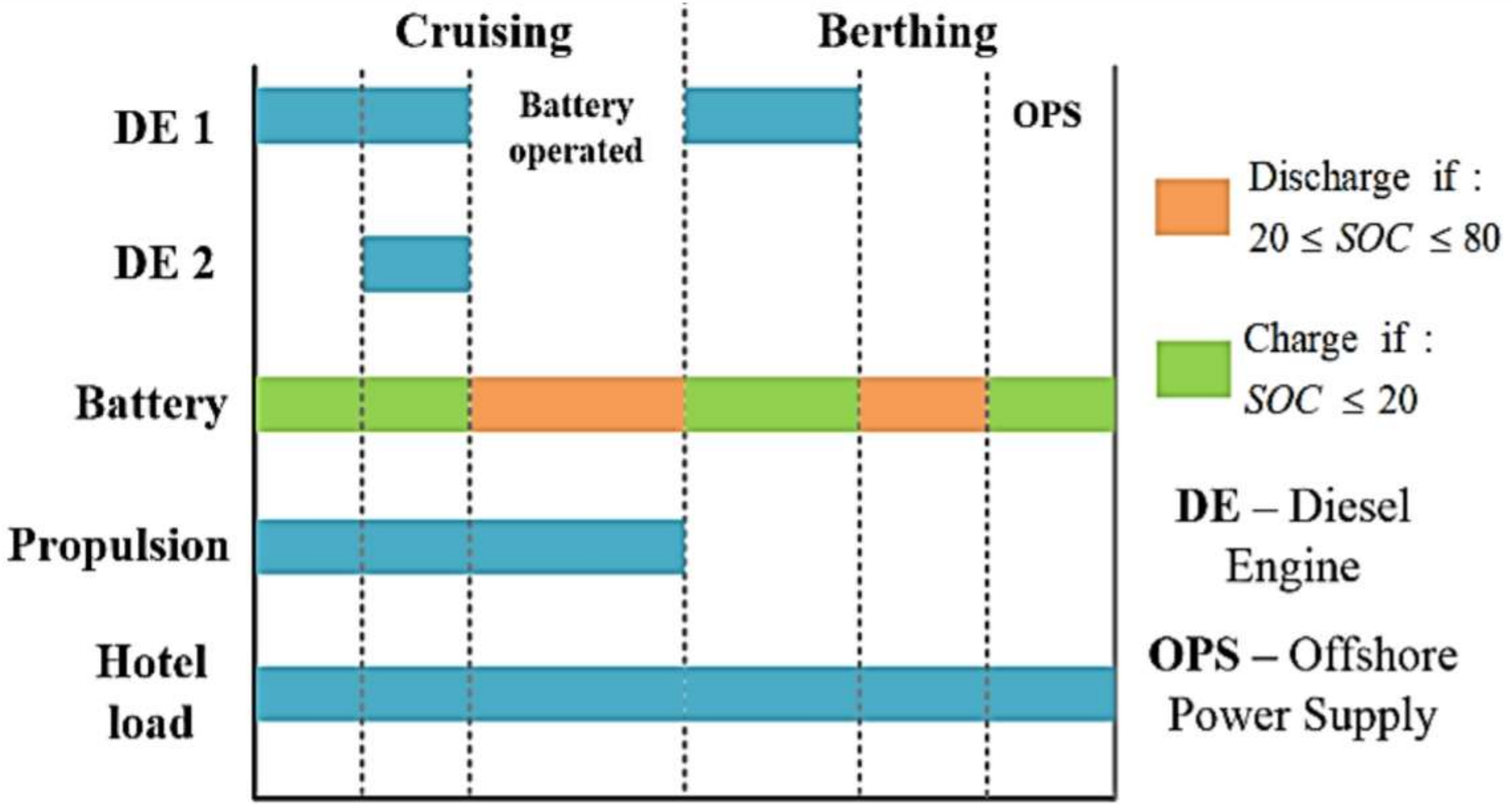
Goal:

1.Output same power as original diesel engine

2.Maximize system efficiency

Source: SOIC

Asia's First Hybrid Electric Ferry



Asia's First Hybrid Electric Ferry

Technical challenges:

- Original old generators are not stable which costs much extra work and budget.
- DC microgrid stability adjustment requires lot of experience and tests.
- Signal interfere within different equipment is a trial and error uncertain process.
- Battery life care strategy.

Non-technical challenges:

- Crew and client have stereotype that motor and battery has no power.
- Hybrid system operation is unfamiliar to crew especially with electric equipment.
- Investment payback time regarding battery life.
- **Silence cruise makes crew feel unconfident.**

Source: SOIC

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EFFICIENSEA project 2014-2018

Off-shore Application of the Flywheel Energy Storage System

AALBORG UNIVERSITY
DENMARK

Den Danske *Maritime* Fond

MAERSK DRILLING

W
WattsUp Power

EFFICIENSEA Project

•WattsUp Power IVS, Martin Speiermann
•Maersk Drilling A/S, Helene Aagaard
• Aalborg University – Department of Energy Technology, Josep Guerrero
Budget: DKK 16 million
Innovation Fund Denmark investment: DKK 8 million
Duration: 3 years

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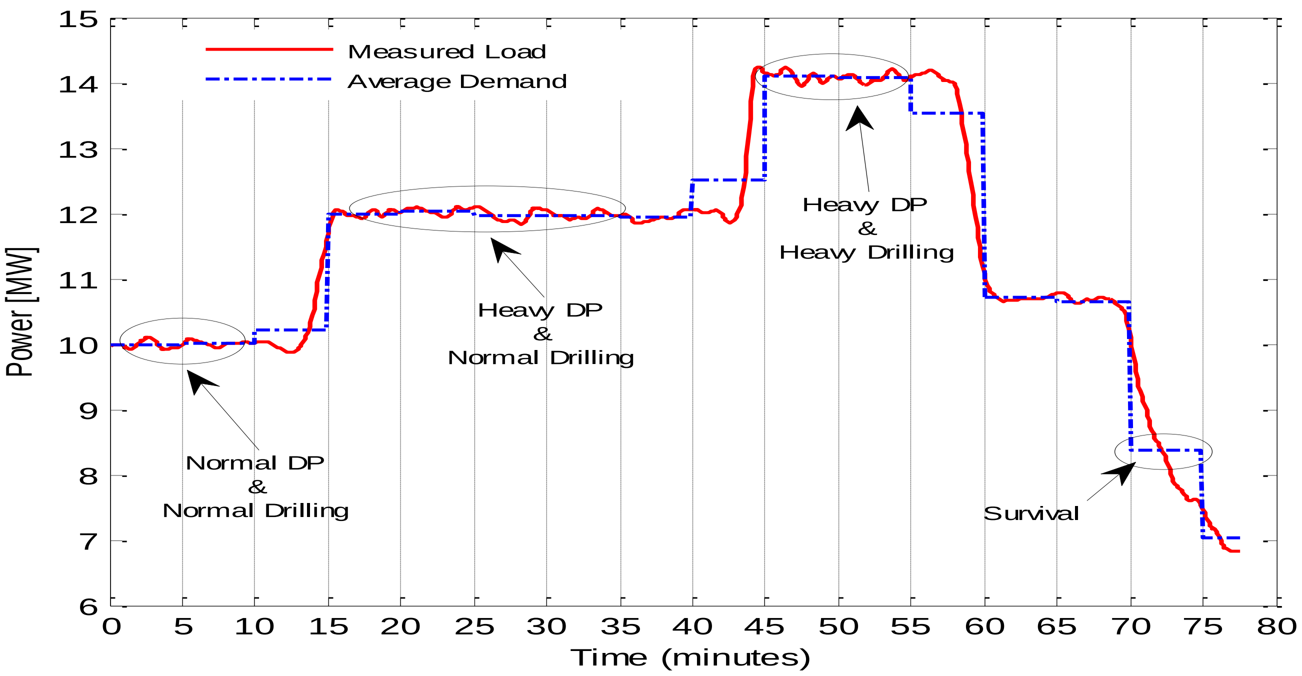
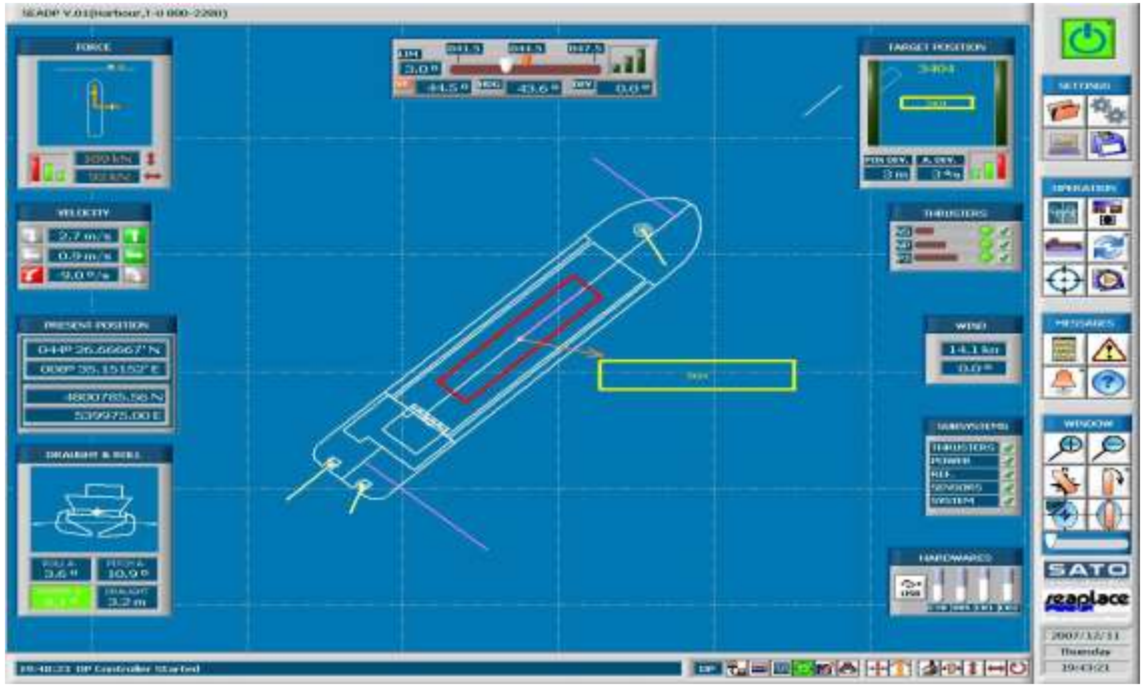
EFFICIENSEA Project

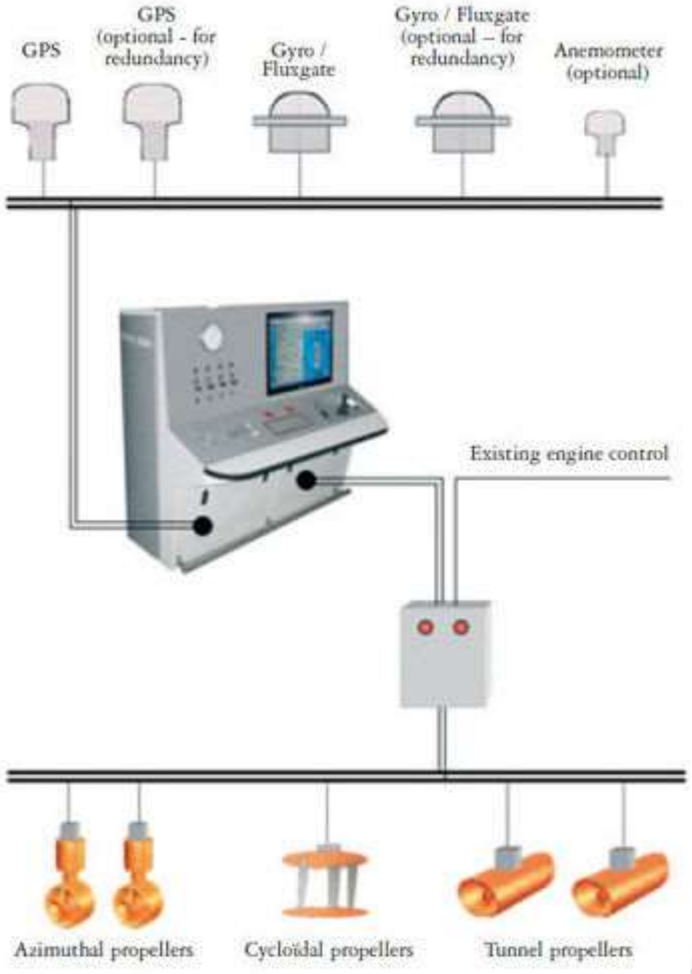




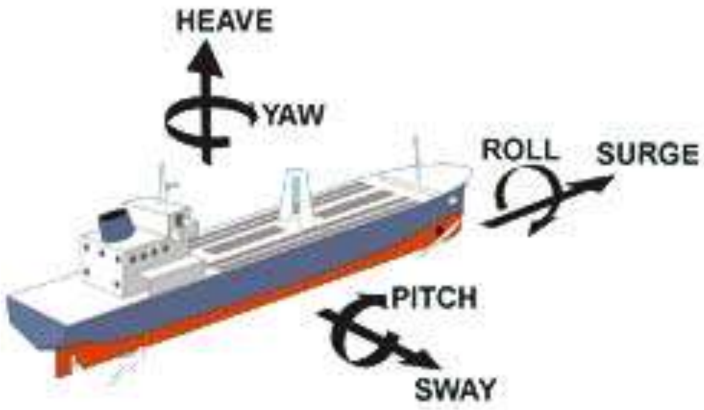
Source: www.flywheel.et.aau.dk

Dynamic Positioning (DP)

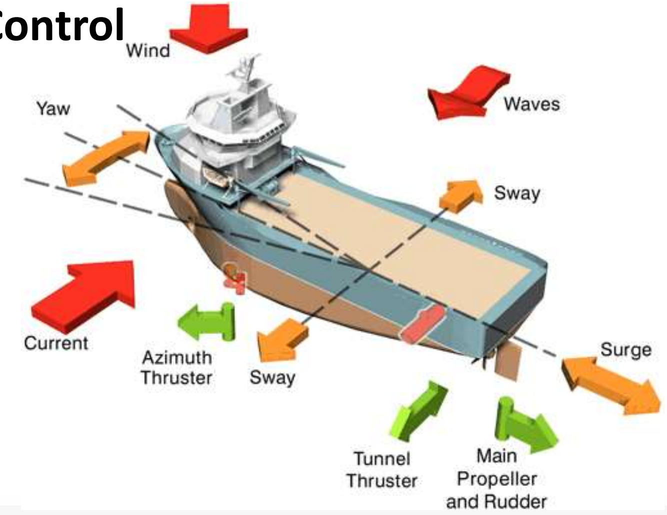
Dynamic Positioning (DP) is a computer-controlled system that automatically maintains a vessel's position and heading.



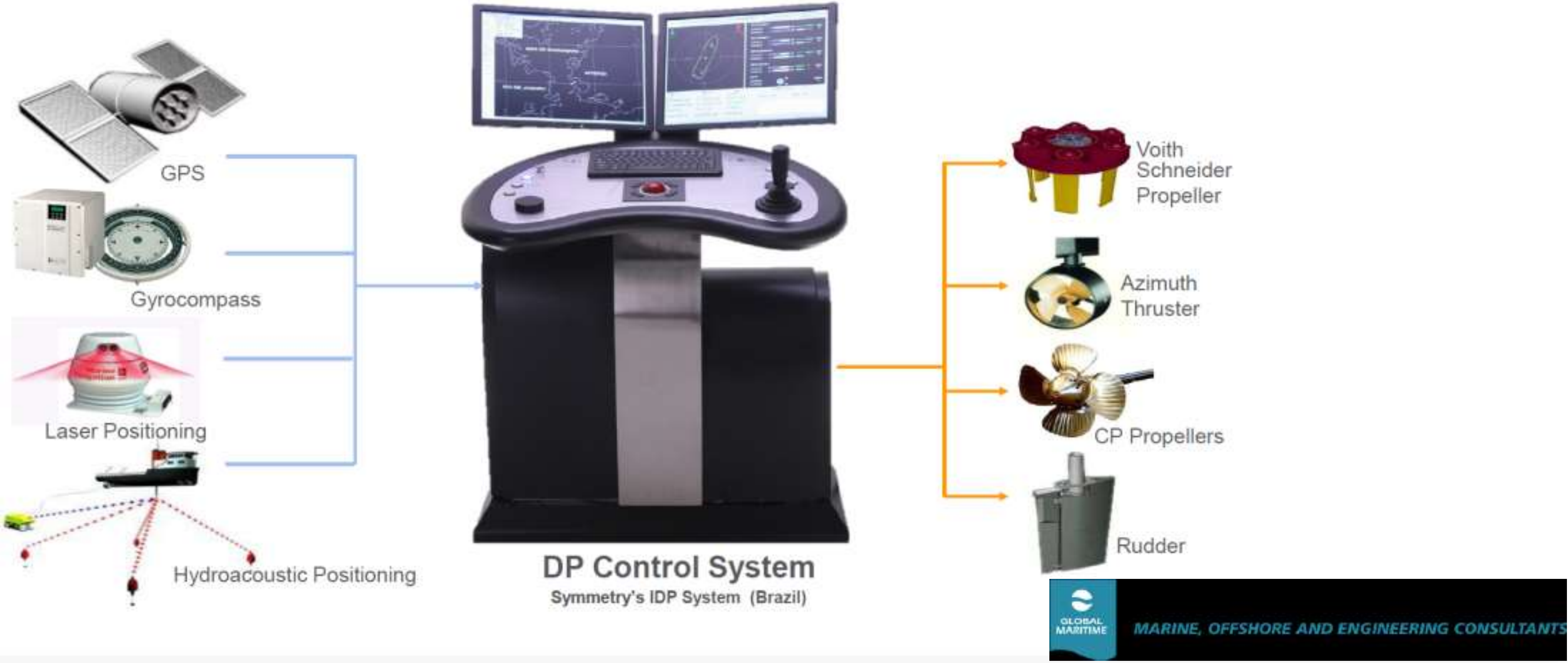
Forces and motions



DP Control



Dynamic Positioning (DP)



Dynamic Positioning (DP)

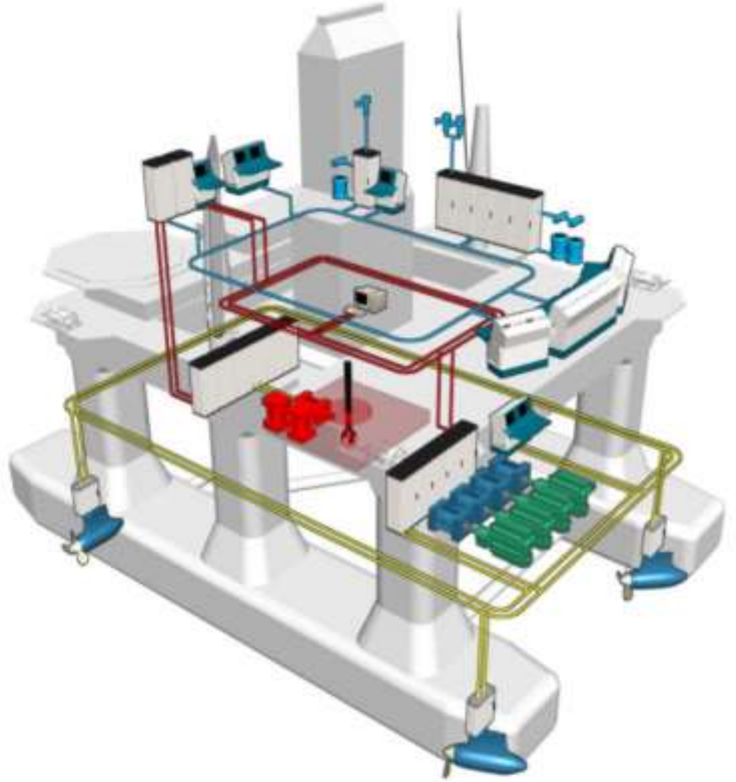
Example of configuration for Dynamic Positioning system

WEST VENTURE
Type:
Semi-submersible
Location:
Norway
Availability:
Available
Maximum depth:
2,600 feet

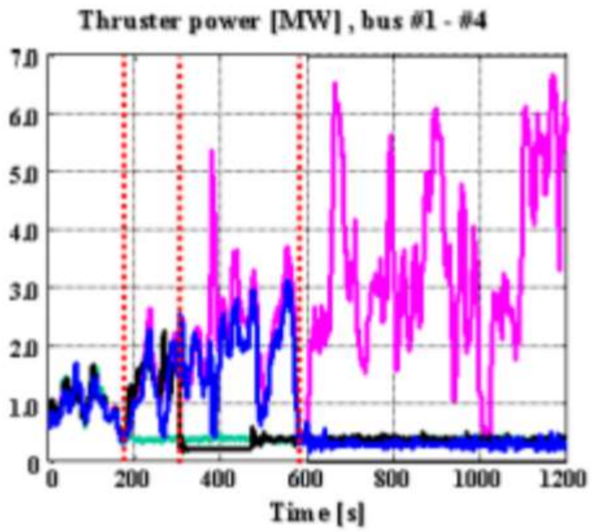
Source: Lauvdal, Trygve, and A. K. Ådnanes. "Power management system with fast acting load reduction for DP vessels." Dynamic Positioning Conference. 2000.

Dynamic Positioning (DP)

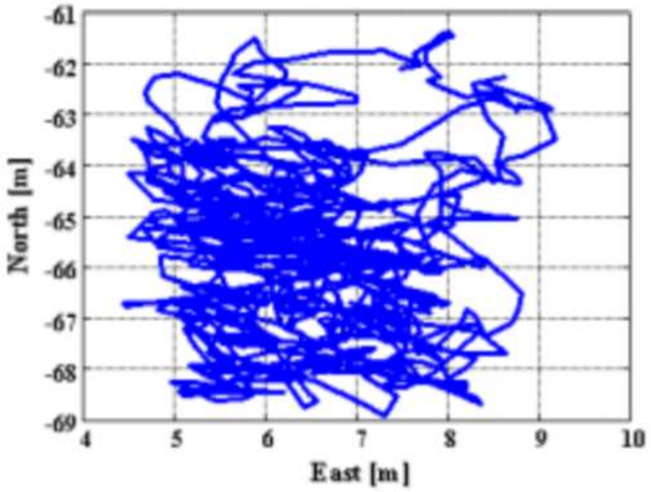
Semi submersible drilling rig with four podded azimuthing thrusters



Full-scale data from West Venture



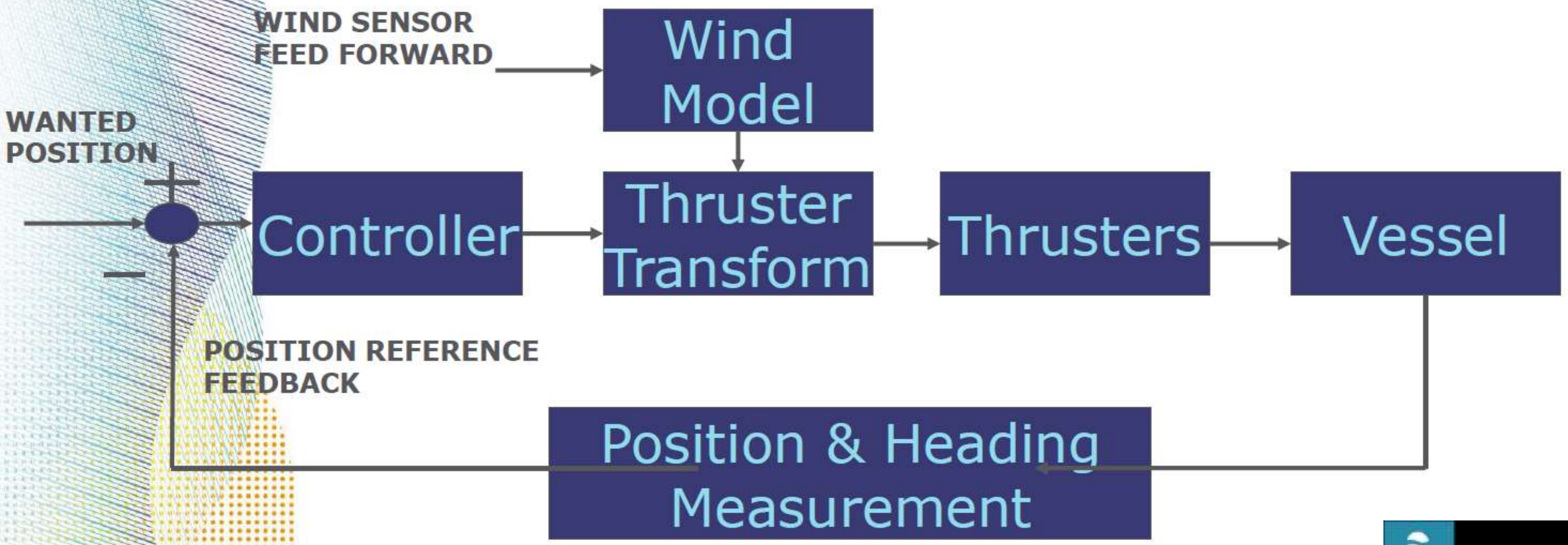
Vessel position.



Dotted lines: when available power on the busses are reduced to 0,3 MW
Solid line: the total thruster power on each bus

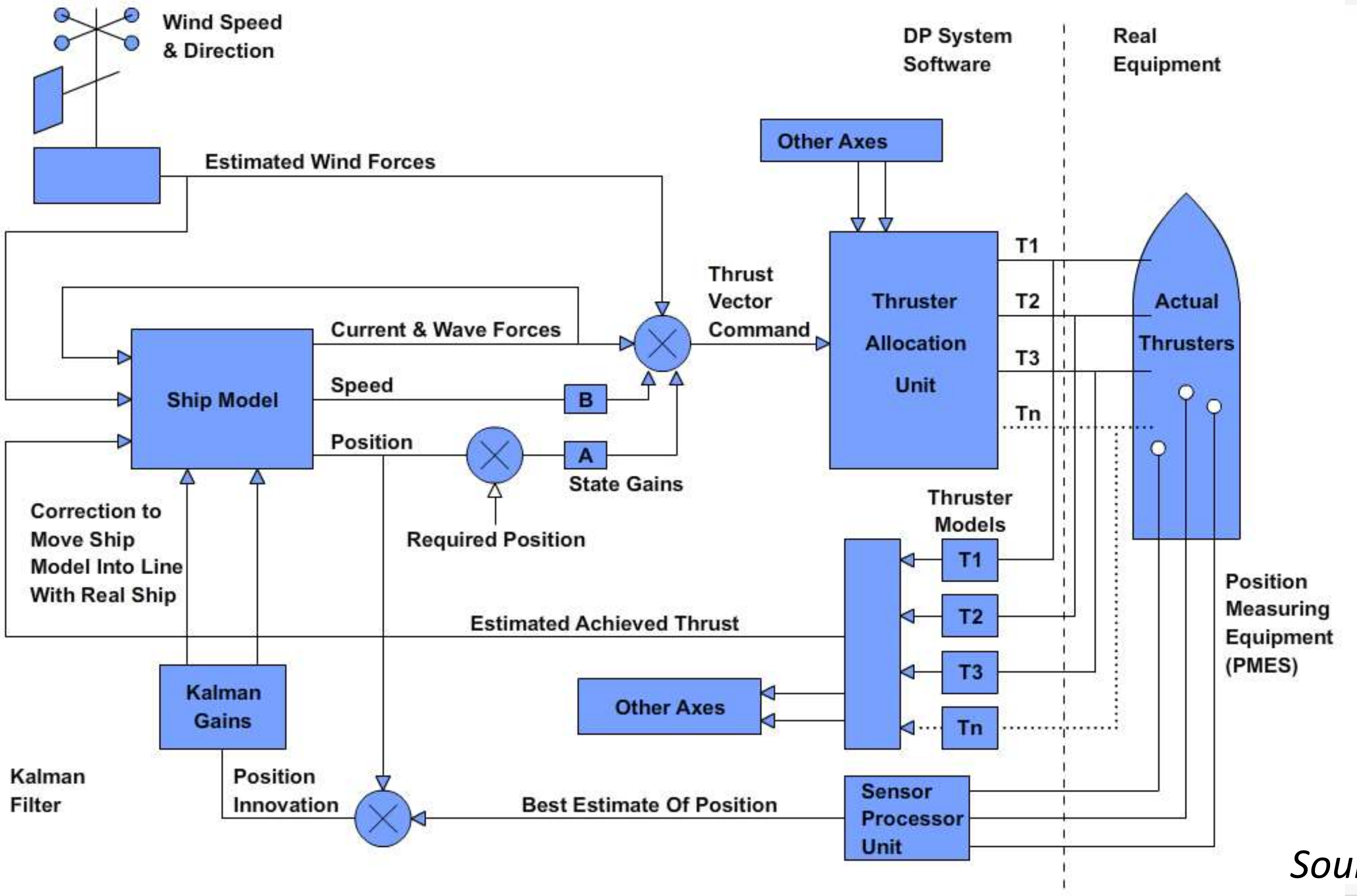
Dynamic Positioning (DP)

DP Basic Control Loop



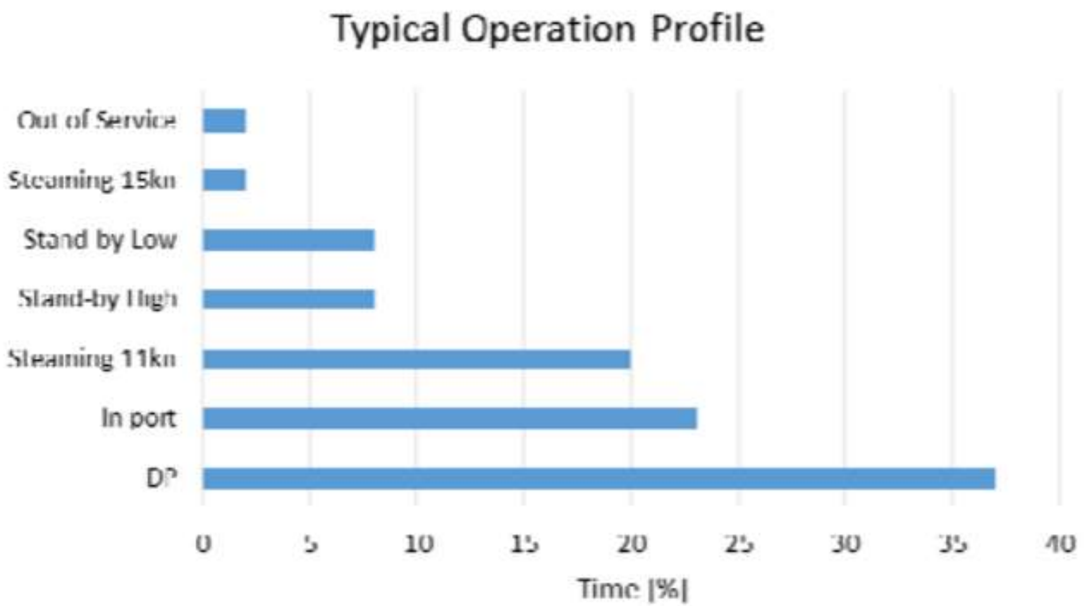
GLOBAL MARITIME MARINE, OFFSHORE AND ENGINEERING CONSULTANTS

Dynamic Positioning (DP)



Source: Pirie & Smith, Ltd, UK

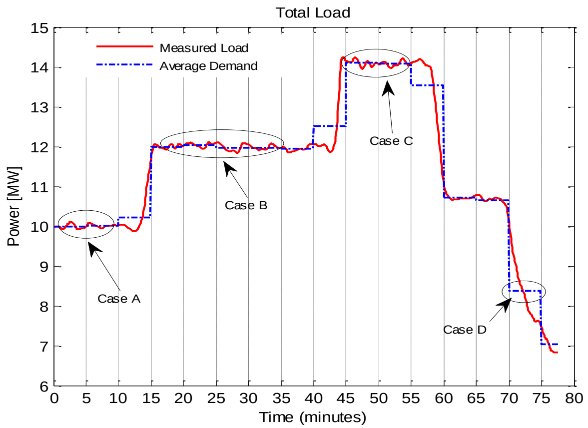
Offshore support vessel OSV example

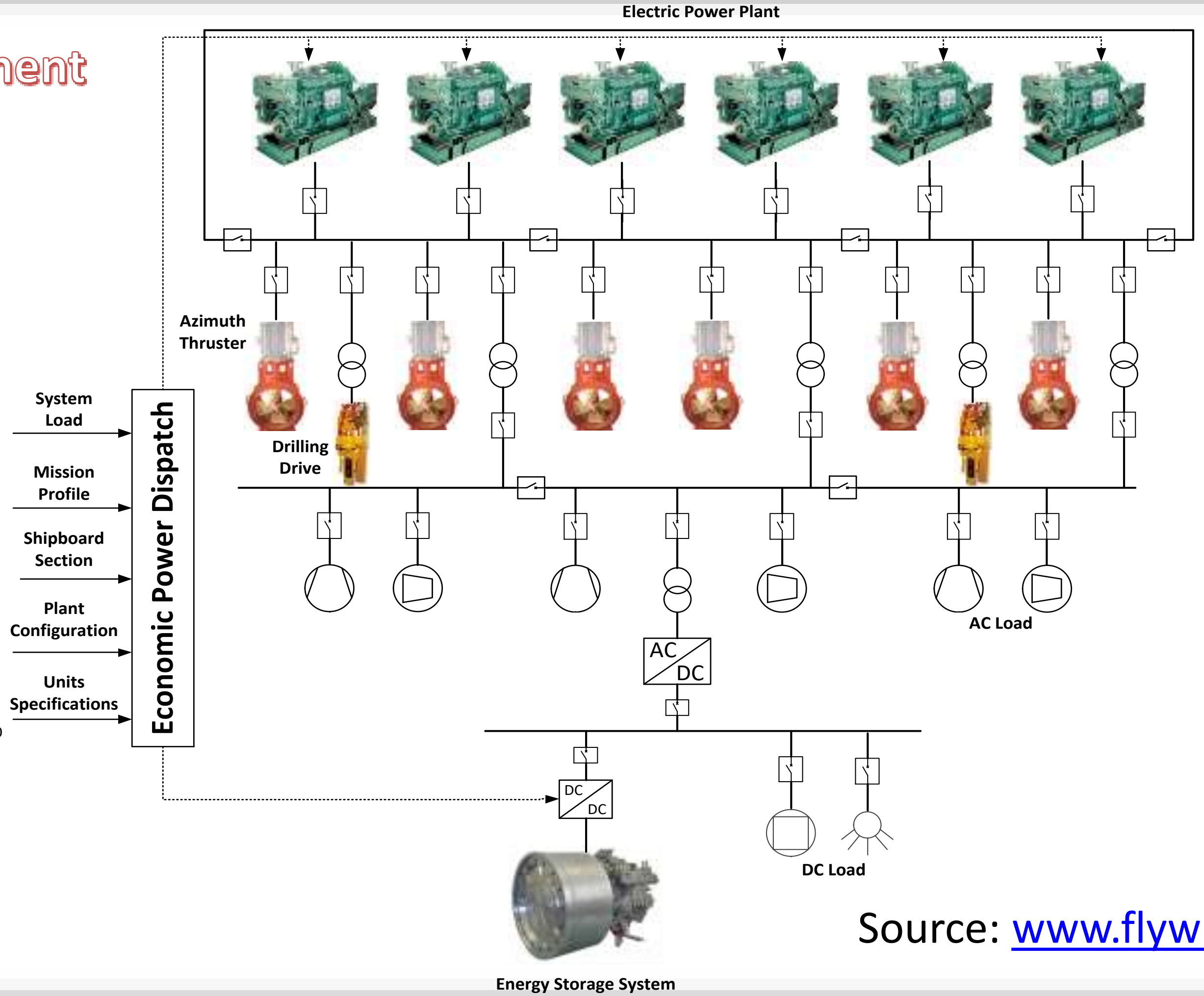


Mode	Time [%]	Power Demand [kW]
DP	37	2128
In port	23	168
Steaming 11kn	20	1836
Stand-by High	8	1000
Stand-by Low	8	755
Steaming 15kn	2	4260
Out of Service	2	0

EFFICIENSEA Project

Phase II: Optimal Operation Management

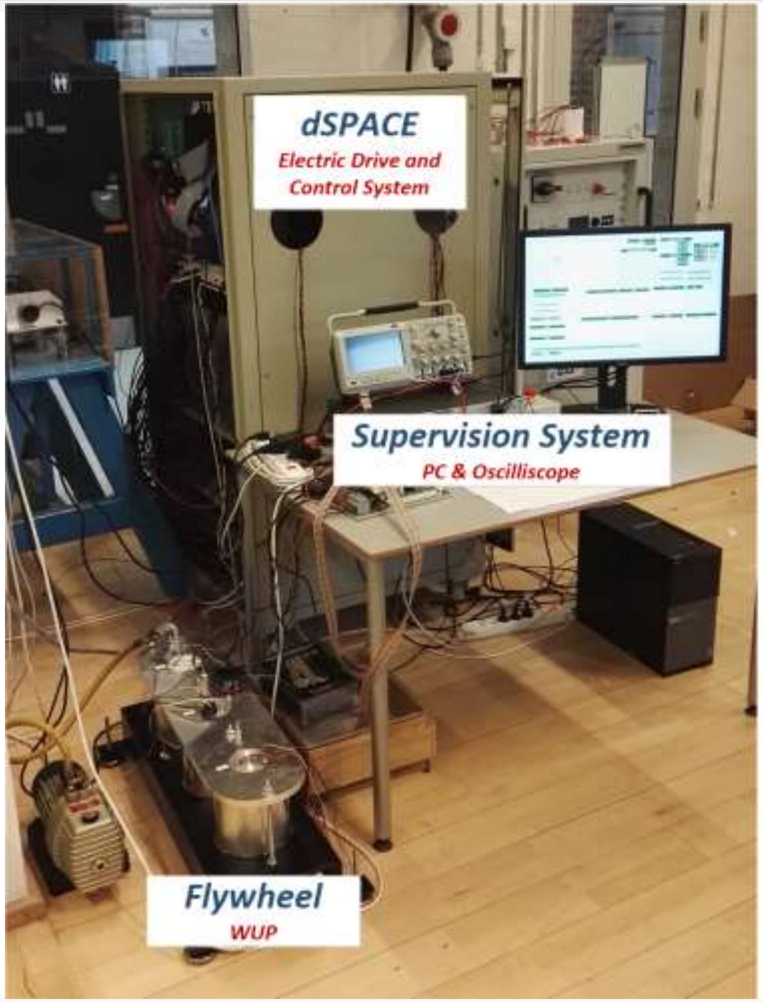




Source: www.flywheel.et.aau.dk

EFFICIENSEA Project

Phase III: HIL Test and Validation



Source: www.flywheel.et.aau.dk

New release: 30 kWh Flywheel

Source: WattsUpPower

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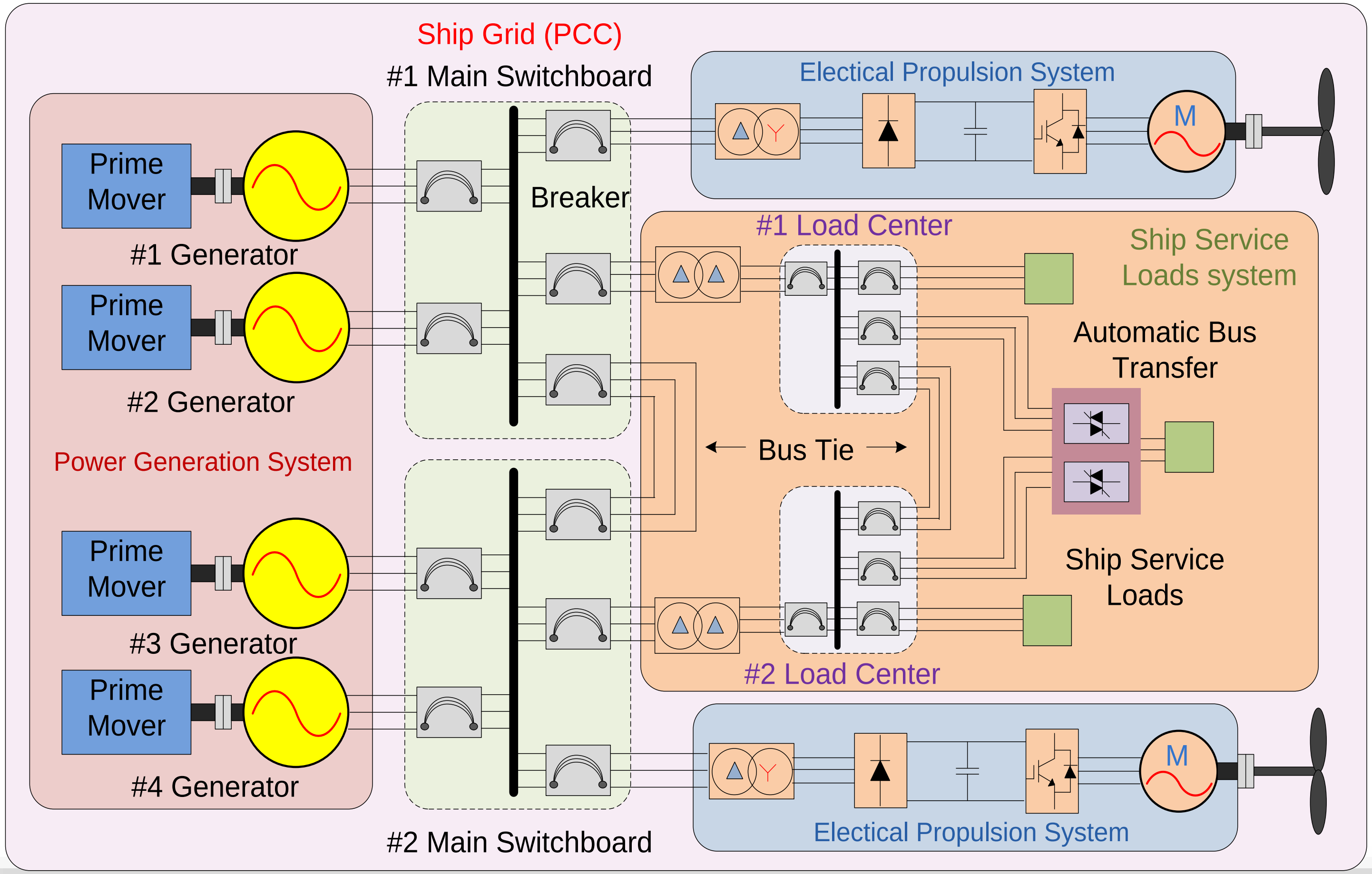
Maritime Microgrid Lab @ AAU

AC Maritime Microgrid Systems



PQ issues

(steady/ transient)

Harmonic/Inter-harmonic

Unbalanced Waveforms

Frequency Variation

Power oscillations

Flickers, Notching and Fluctuation

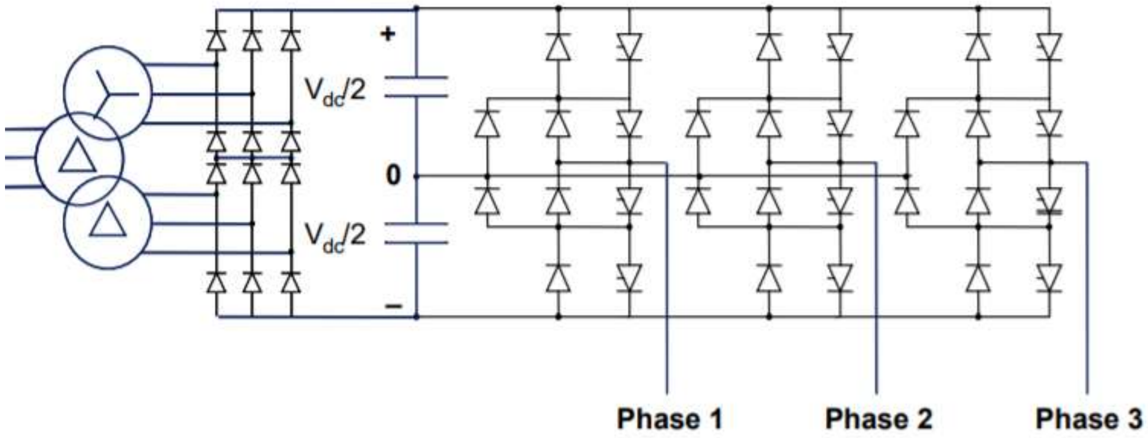
Power flow/Power sharing

Protection

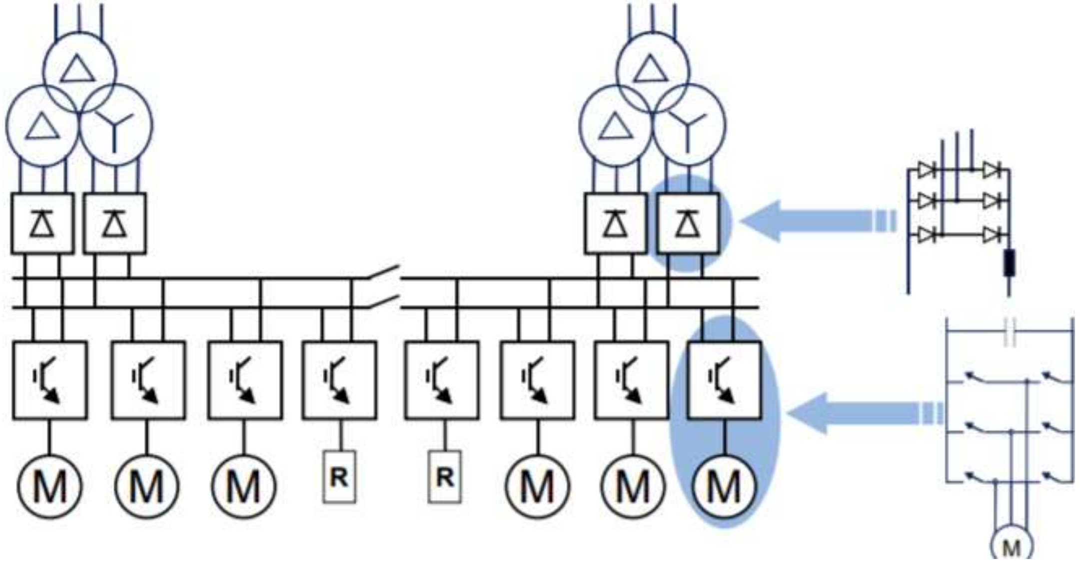
Harmonics

12-pulse Voltage Source Inverter (VSI)

a) Medium voltage single drive for thrusters



b) Low voltage drilling multidrive



Source: Adnanes, Alf Kare. "Status and inventions in electrical power and thruster systems for drillships and semi-submersible rigs." proceedings of the Dynamic Positioning Conference. 2004.

PQ Standards in SPS

Several Standards for SPS

PERMITTED LEVELS OF VOLTAGE AND FREQUENCY DEVIATIONS FOR SHIP POWER SUPPLY SYSTEMS

Standards	Instruments and Parameter Variations				
	Range of The Standard	**Voltage**	**Frequency**	**Total Harmonic Distortion**	**Individual Harmonic Distortion**
Polish Register IEC60092-101	Electrical Installations in ships. Definitions and general requirements	+6%,−10% ±20%(1.5s)	±5% ±10%(5s)	5%(40th)	3%
Lloyd's Register	Selection and Use of Standards for Naval Ship	+6%,−10% ±20%(1.5s)	±5% ±10%(5s)	8%(50th)	1.5%
STANAG1008	Characteristics of Shipboard Electrical Power Systems in Warships of the North Atlantic Treaty Navies, NATO, Edition9, 2004	±5% ±16%(2s)	±3% ±4%(2s)	5%(40th)	3%
American Bureau of shipping 2008	Rules of International Ship Classification Societies, eg PRS/25/P/2006	+6%,−10% ±20%(1.5s)	±5% ±10%(5s)	5%(40th)	3%
IEEE Std.45-2002	IEEE Recommended Practice for Electrical Installations in ships	±5% ±16%(2s)	±3% ±4%(2s)	5%(40th)	3%

PQ issues in maritime microgrids

Harmonic mitigation solutions

While variable speed drives help optimize production, save energy and extend equipment lifetime, they also introduce harmonic currents to the on-board grid. Many applications in the industry require a low level of harmonic distortion. Regulations have been imposed by marine certification bodies which state that harmonics must be kept to 5% or 8% of the total harmonic voltage distortion (THDv) on the main bus bar.

Danfoss Drives' wide range of mitigation solutions which can help restore weak networks, increase network capacity, meet compact retrofit demands or secure sensitive environments includes:

- **VLT® Advanced Active Filter AAF 006**
- **VLT® Advanced Harmonic Filter AHF 005/AHF 010**
- **VACON® NXP AFE**

Source: Danfoss

Poland – Denmark Cooperation PhD Project 2017

Unbalance and Harmonic Analysis in Shipboard Microgrids

AALBORG UNIVERSITY
DENMARK

GDYNIA MARITIME UNIVERSITY
1920
POLAND

Horizon II

Ship

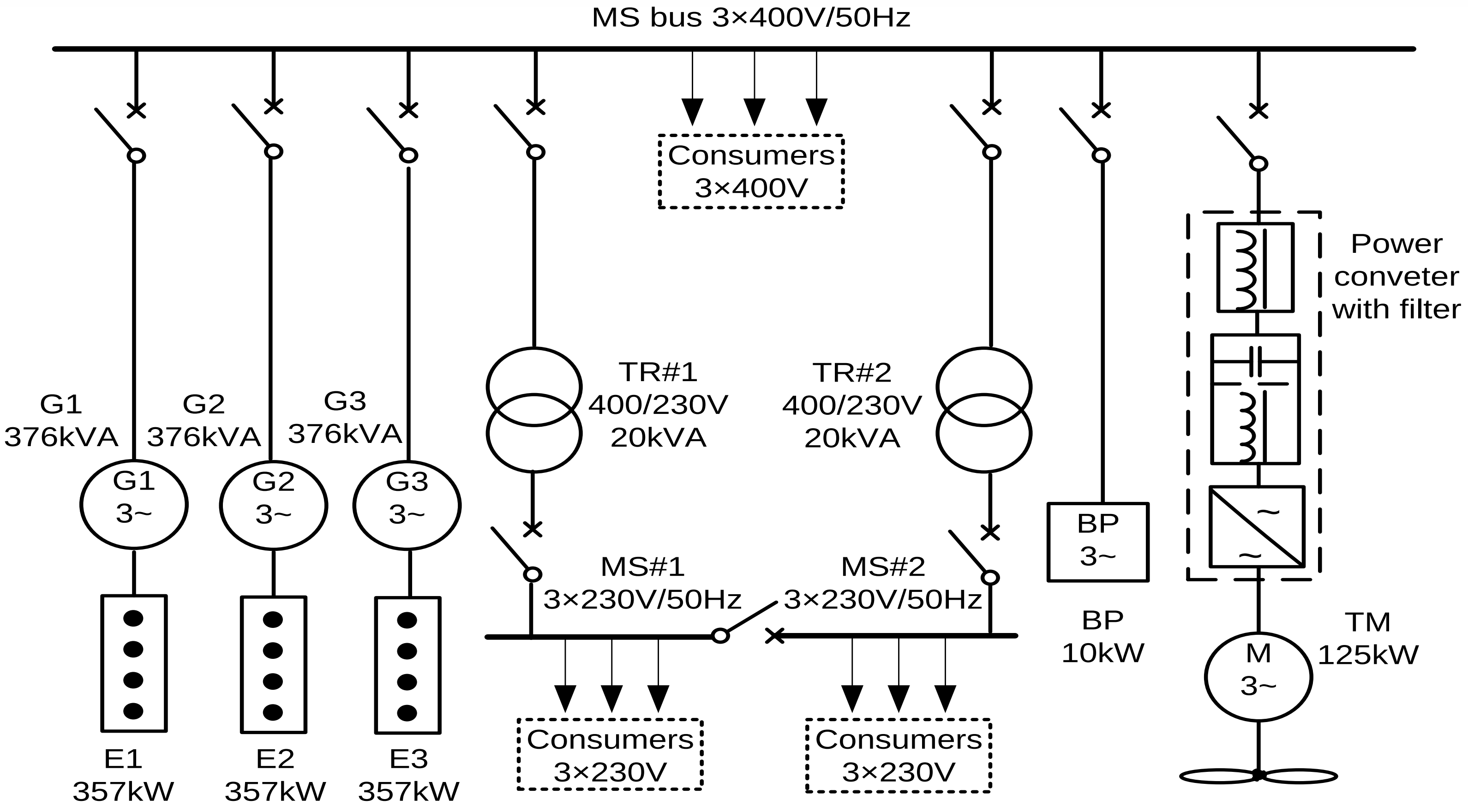
Engine room

Control board

Diesel generator

Pump

Horizon II

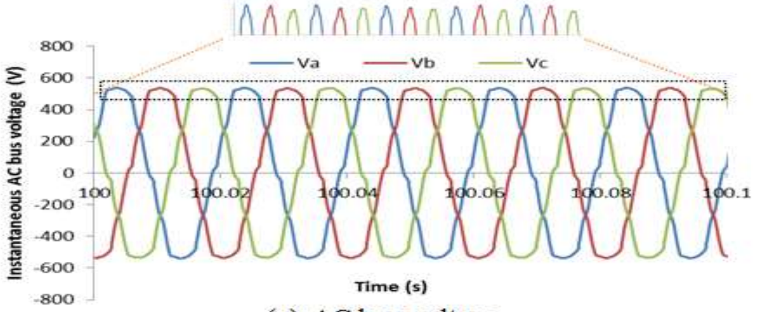


(2)

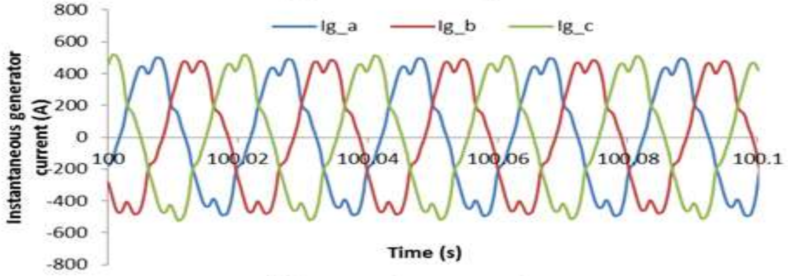
Fig .1 The industrial AC MMGs based on Horizon II ship

Comparison:

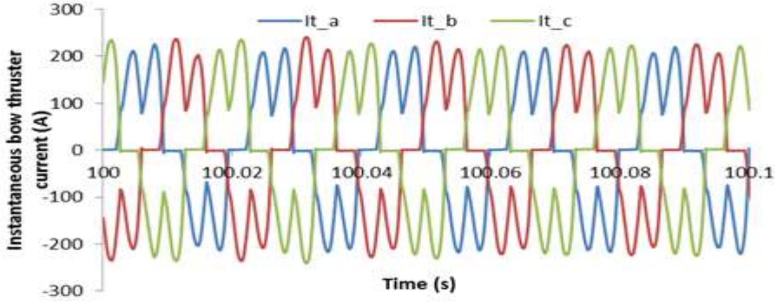
Balanced SPS



(a) AC bus voltage

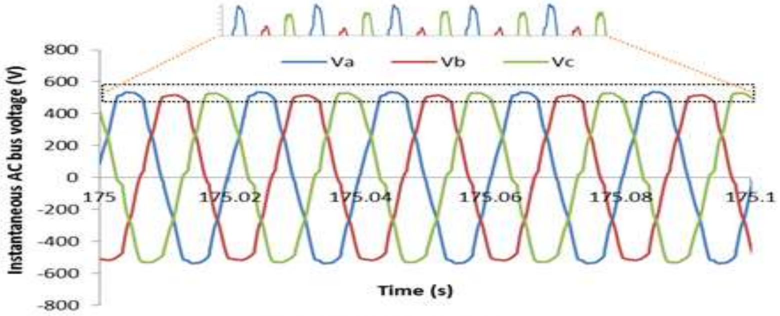


(b) generator current

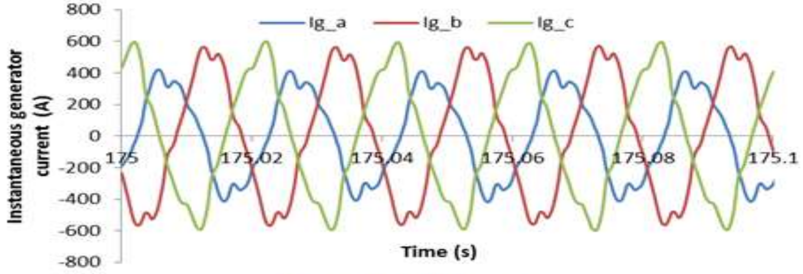


(c) bow thruster current

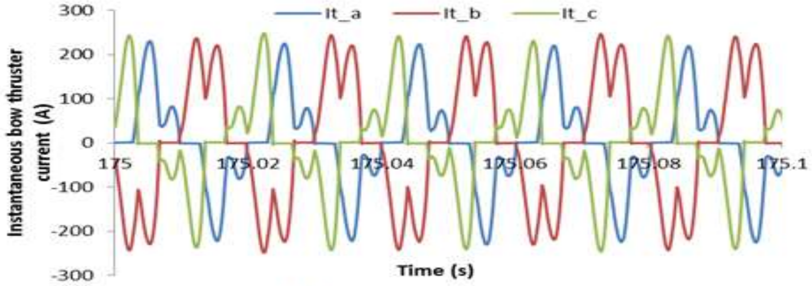
Slightly Unbalance SPS (UF=1.5%)



(a) AC bus voltage



(b) generator current



(c) bow thruster current

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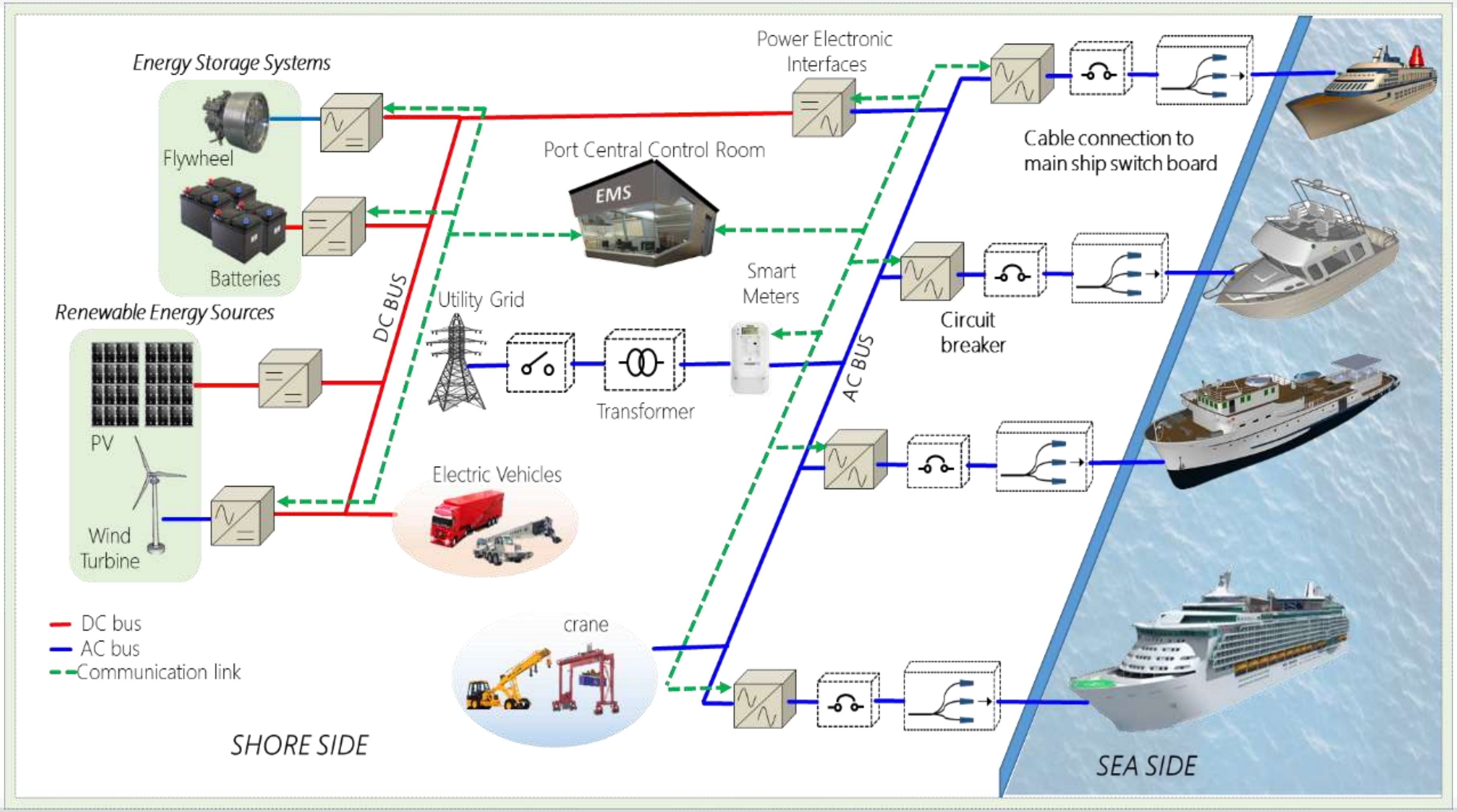
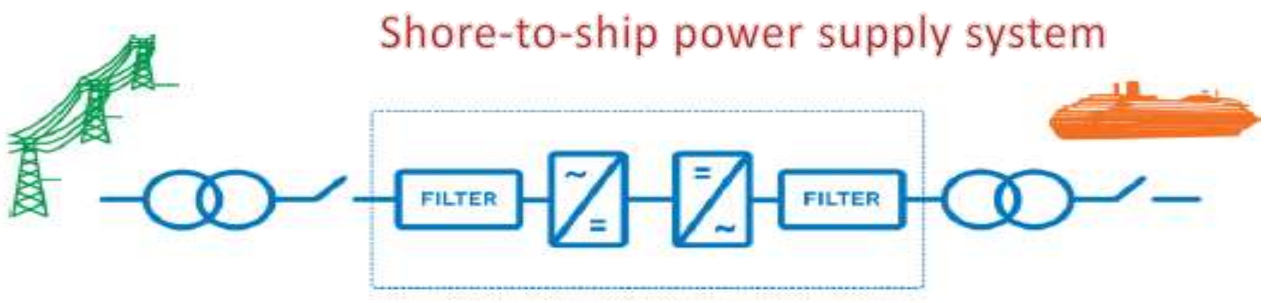
Seaports

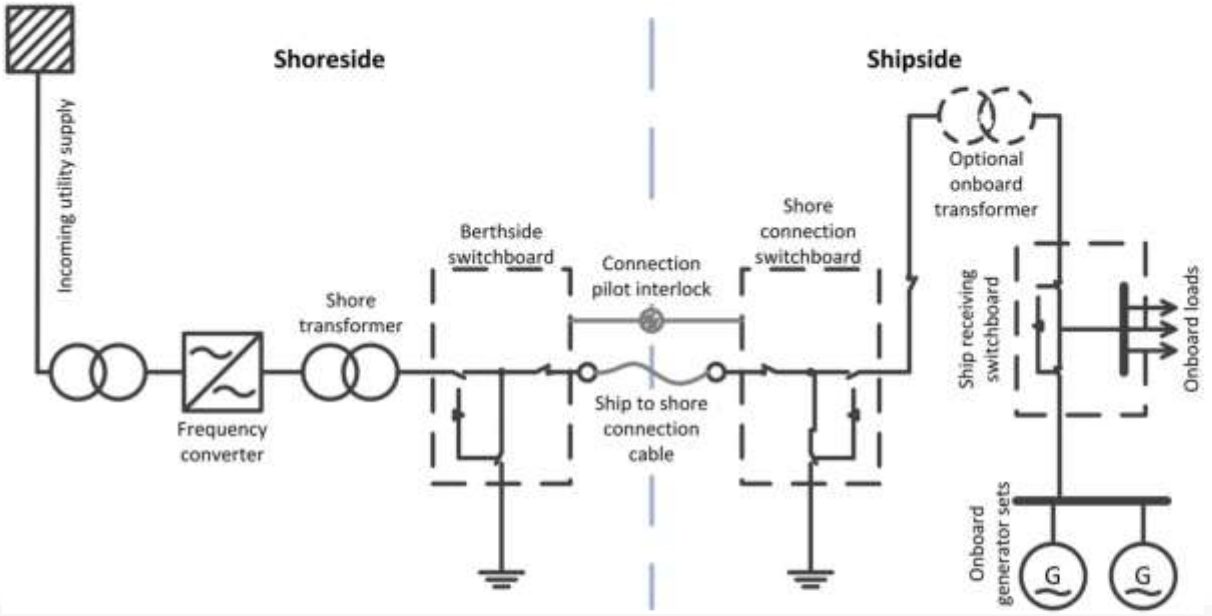


Energy Storage Systems
Flywheel
Batteries
Renewable Energy Sources
PV
Wind Turbine
DC BUS
Power Electronic Interfaces
Port Central Control Room
EMS
Utility Grid
Transformer
Smart Meters
AC BUS
Electric Vehicles
crane
Cable connection to main ship switch board
Circuit breaker
DC bus
AC bus
Communication link
SHORE SIDE
SEA SIDE

Cold Ironing

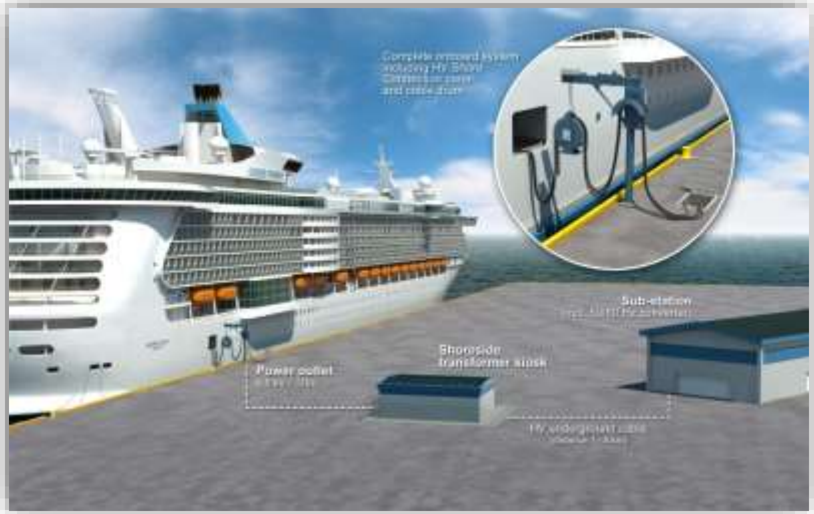
- Change grid frequency from 50Hz to 60Hz and synchronize with ships grid.
- Reduced local emissions, noise and vibrations
- Increased lifetime for ships engines
- Allow maintenance on the ships engines during the harbour stay
- Bi-directional: Generator load test power can be fed back to the shore grid – complying to local grid code



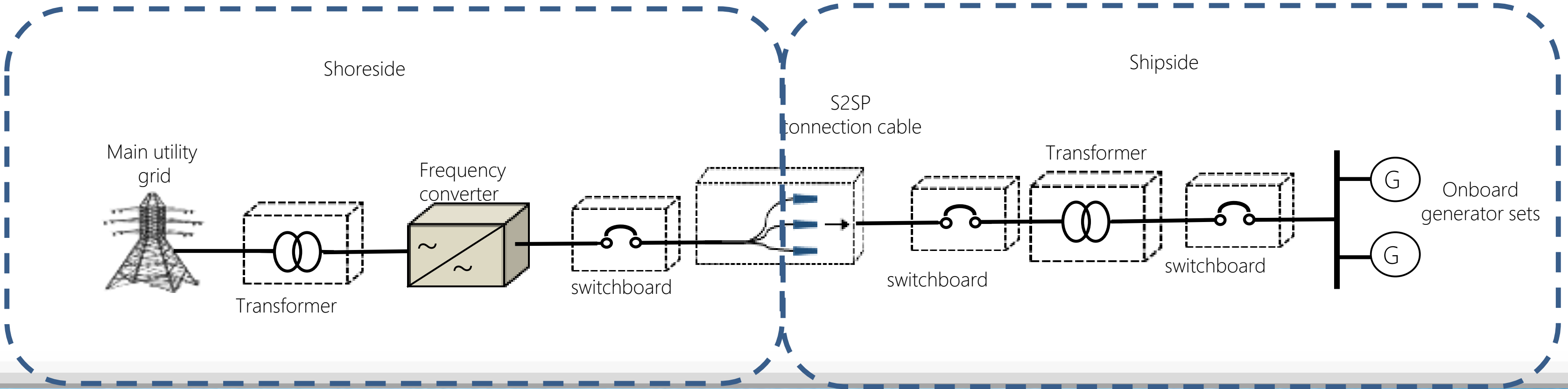


Source: Vacon Power / Danfoss

Cold Ironing

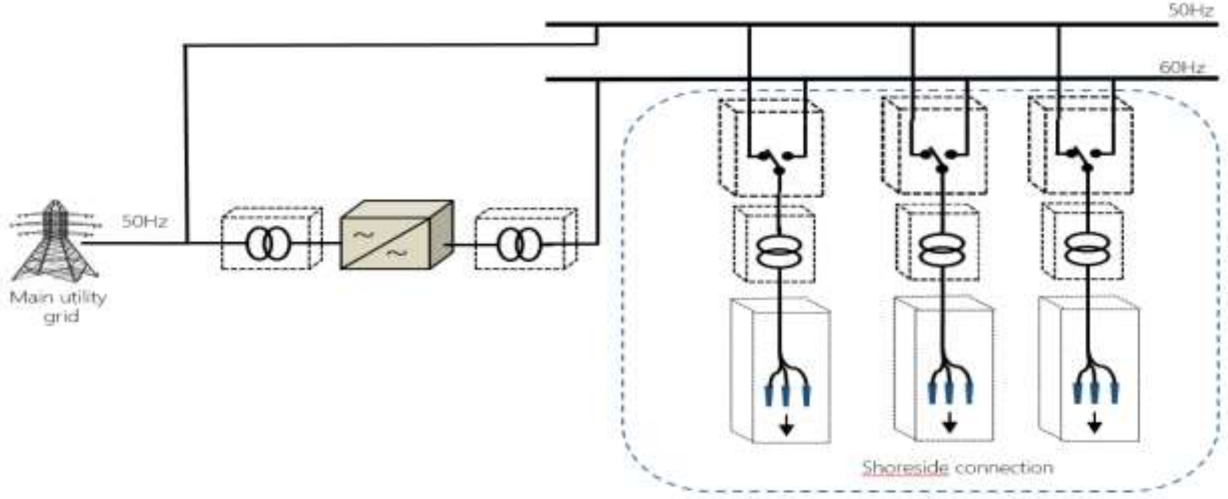


Generic cold ironing standard requirement



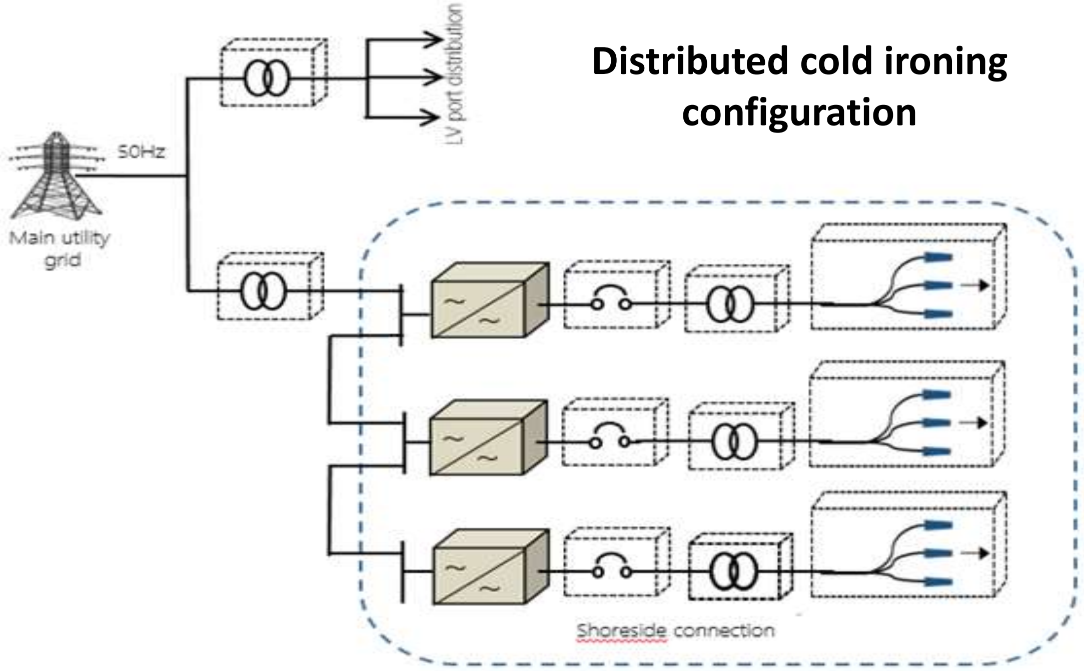
Cold Ironing

Centralised cold ironing configuration



- Used one frequency converter as a central and double busbar to allowed the ship berthing either 50Hz or 60Hz.

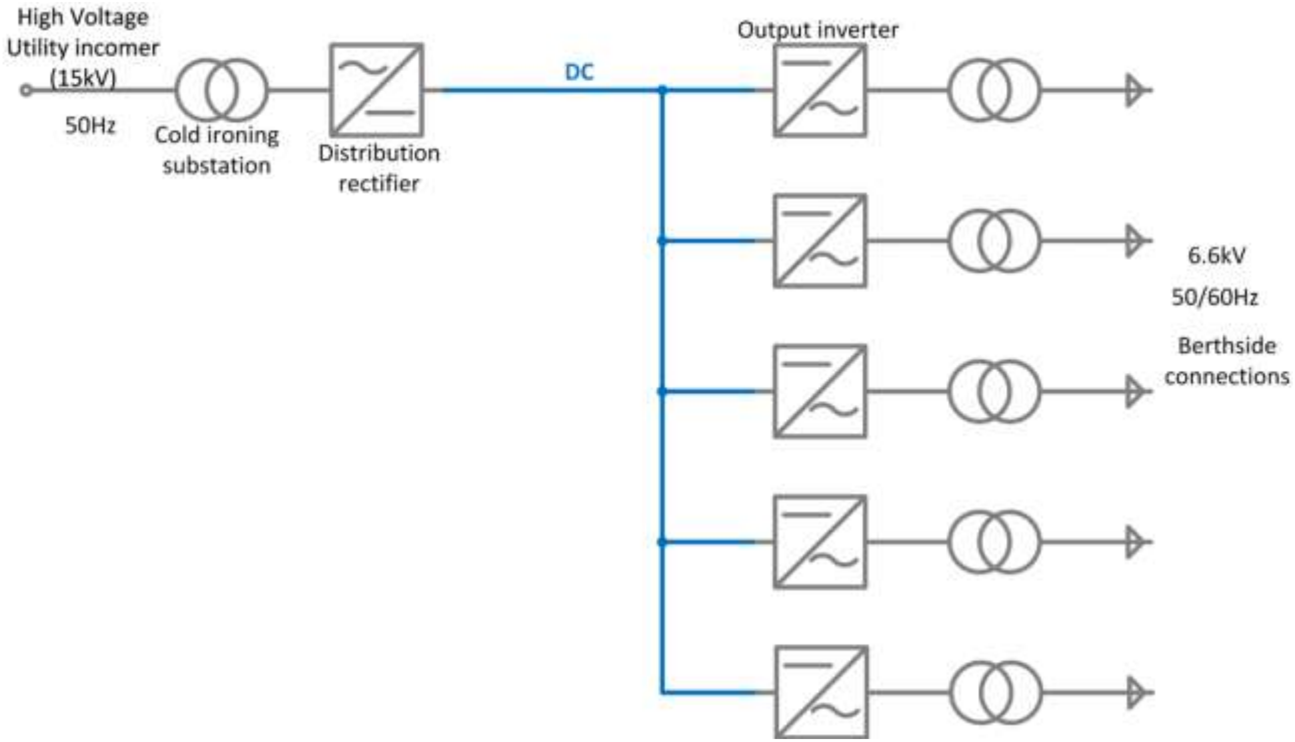
Distributed cold ironing configuration



- Directly extend the system by replicates the complete regime of each berth with frequency converter and transformer.
- Excellent flexibility and redundancy
- High costing

Cold Ironing

DC distribution configuration



- By extending of two previous configuration with introducing DC bus.
- Easier to integrate with any energy storage device
- Able to use in small quay area

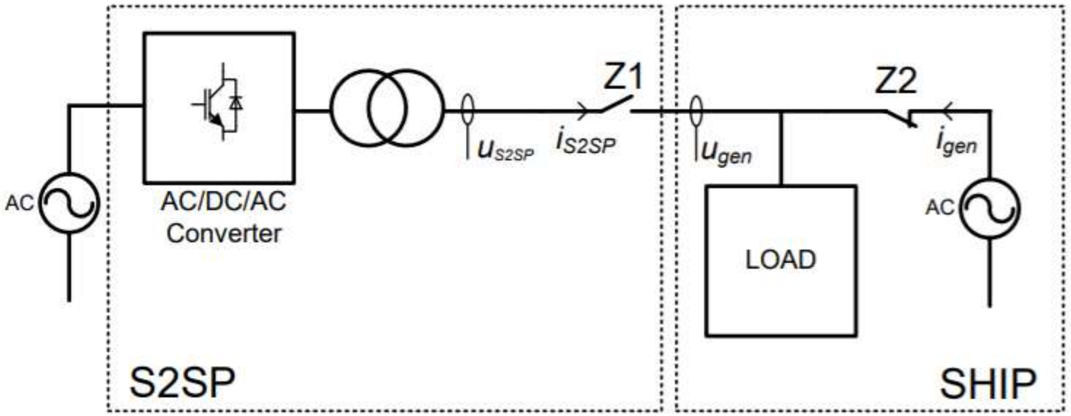
E. A. Sciberras, B. Zahawi, D. J. Atkinson, A. Juando, and A. Sarasquete, "Cold ironing and onshore generation for airborne emission reductions in ports," Proc. Inst. Mech. Eng. Part M J. Eng. Marit. Environ., vol. 230, no. 1, p. 1475090214532451, 2014.

Cold Ironing

Synchronization

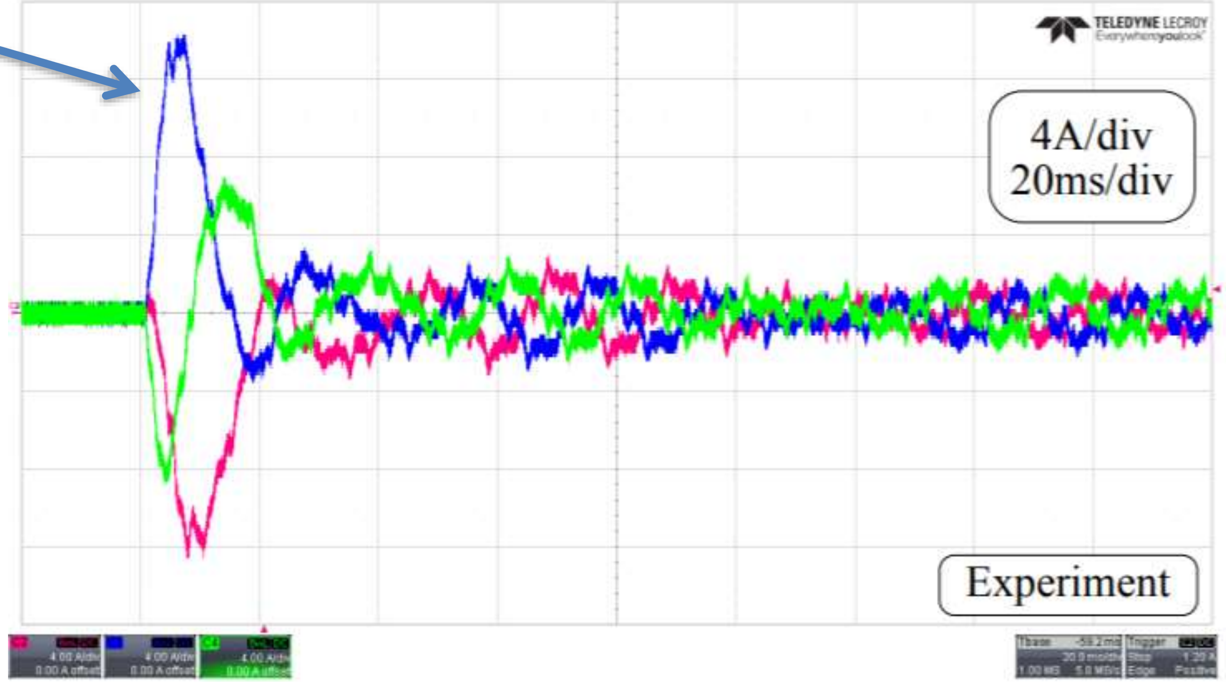
If Ship tries to synchronize bulky DG with the shore, huge inrush currents appear due to inertia

Simplified block scheme of S2SP system



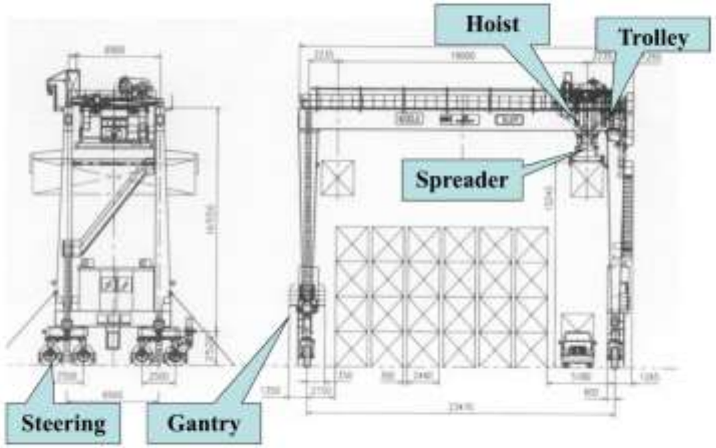
SP2S case

Phase currents of the synchronous generator during synchronization with low voltage AC grid

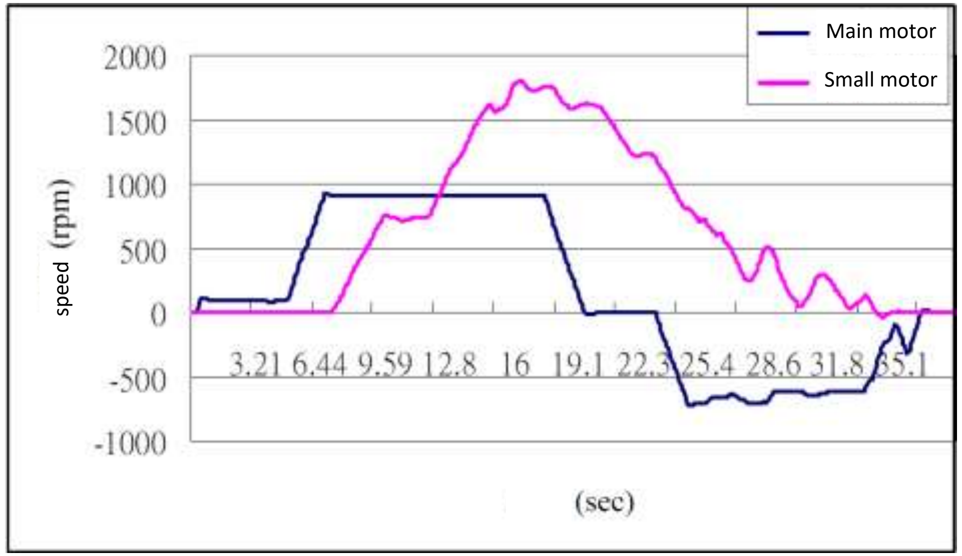


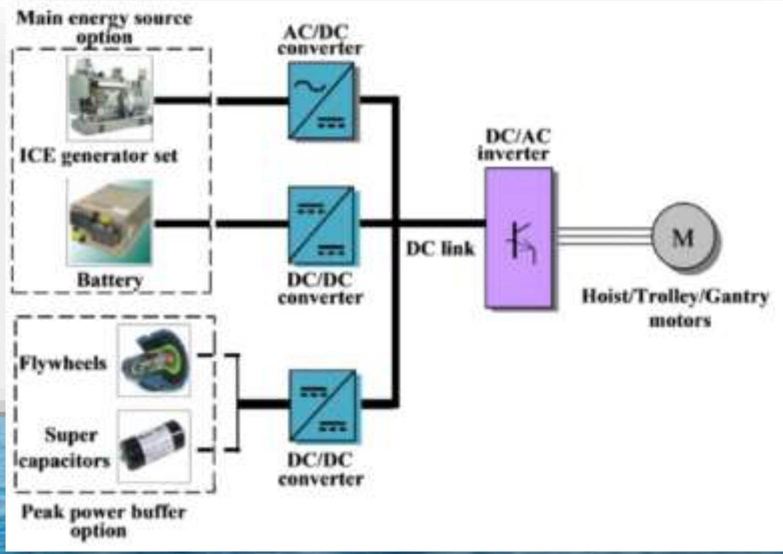
Source: Ship-to-Shore vs. Shore-to-Ship Synchronization Strategy, R. Smolenski, et al., IEEE TEC, 2018

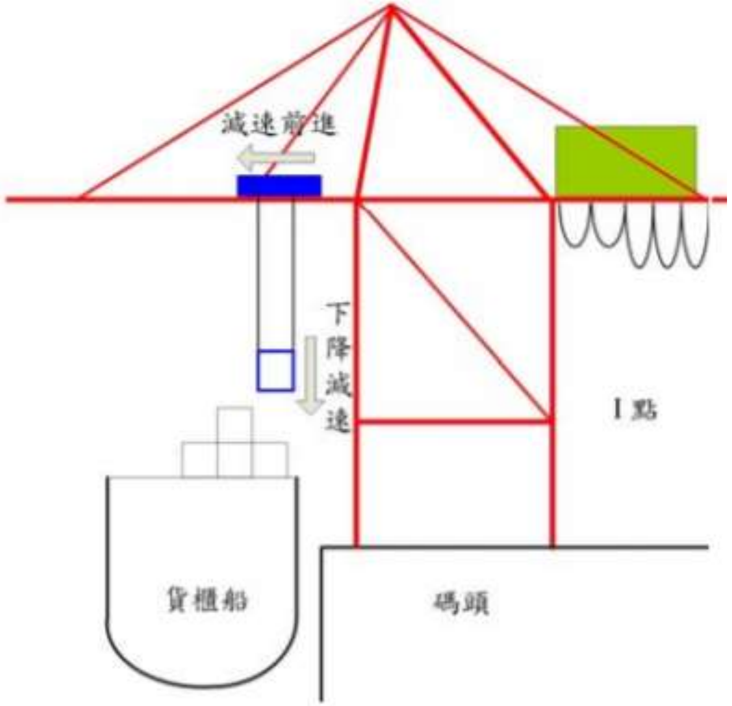
Port Cranes



Port Cranes

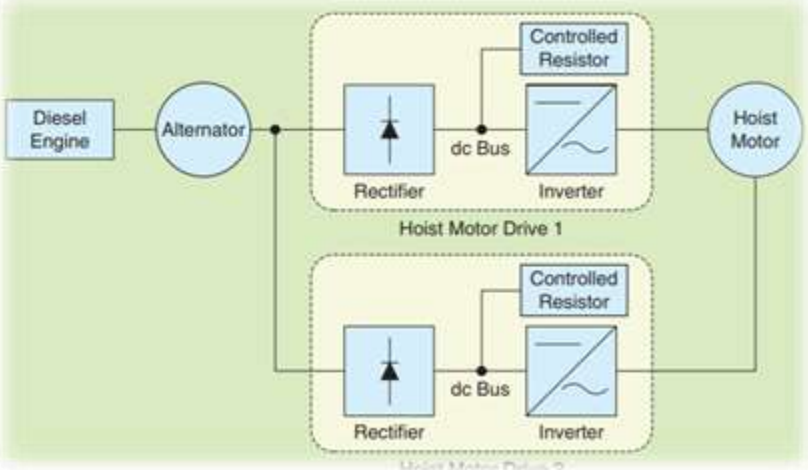


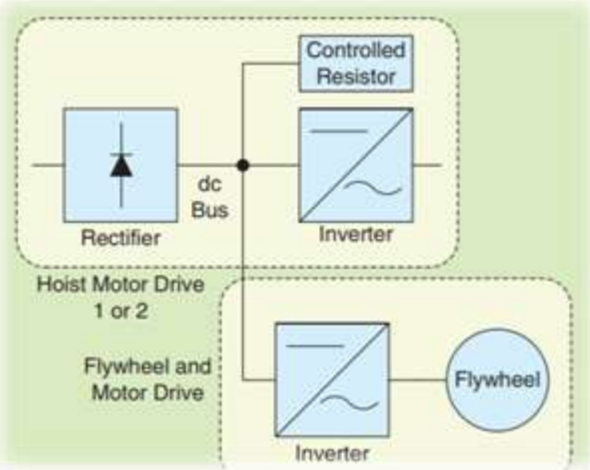


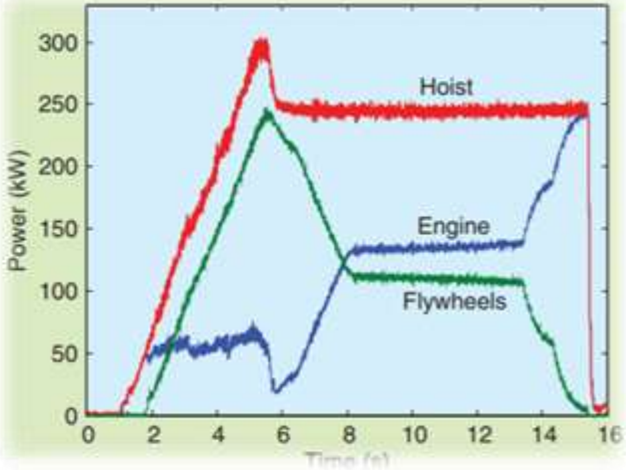


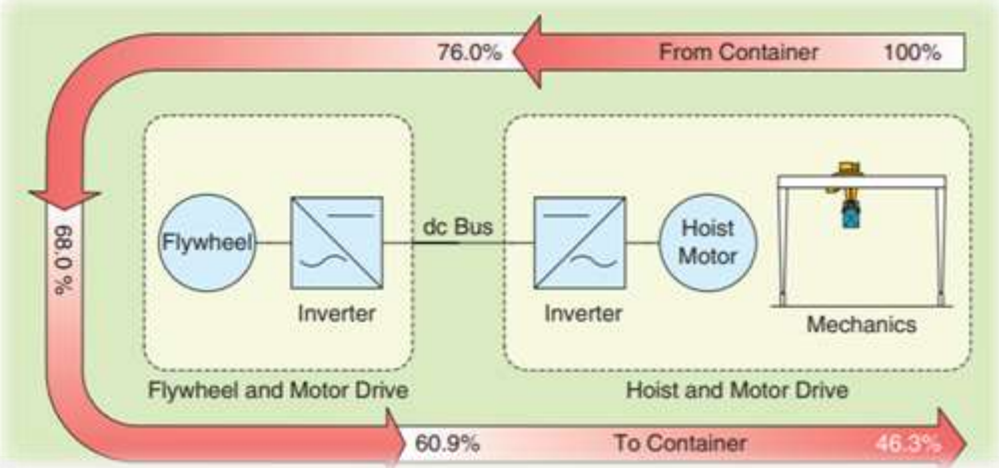
Source: Nan Zhao, Nigel Schofield, and Wangqiang Niu
Energy Storage System for a Port Crane Hybrid Power-Train
IEEE TRANSACTIONS ON TRANSPORTATION ELECTRIFICATION, VOL. 2, NO. 4, DECEMBER 2016

Port Cranes









- +45% Energy recovery
- Possibly DC microgrid config.
- Coordination between FW
- Savings and…
- Power peak reduction

Source: *Flynn, Mark M., Patrick McMullen, and Octavio Solis. "Saving energy using flywheels." IEEE Industry applications magazine14.6 (2008).*

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Ongoing PhD maritime projects

- Integration of Microgrid Technologies In Future Seaports - Nor Baizura Binti Ahamad
- Energy Management System in Shiphoard Microgrids - Muzaidi Bin Othman
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