



Microgrid Technologies for Terrestrial and Maritime Applications

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ESCOIA UNIVERSITARIA D'ENGINYERIA TECNICA INDUSTRIAL



Yes Josep, but who are you?



- Born in Barcelona
- Active ecologist from early years
- “Sabatic” year before University
- BSc in Telecom 1993-1997
- MSc in EE 1997-2000
- PhD PE&C in UPS Company 2000-2003
- Studied Jazz in the Official School of Music 2003-2007
- Postdoc in Zhejiang University, China 2007
- Studied Chinese in the official School of language 2007-2011
- Move from Barcelona to Aalborg 2011

After years of researching the sex of microgrids... I decided to become a customer

PV 2.4 kW

Selling EL: 1.02 kr/kWh

Buying EL: 2.20 kr/kWh



EV
30 kWh
250 km

EV Charger
3.7 kW

Like a doctor taking your own pills...

Dr House?

(again) it's Lupus!

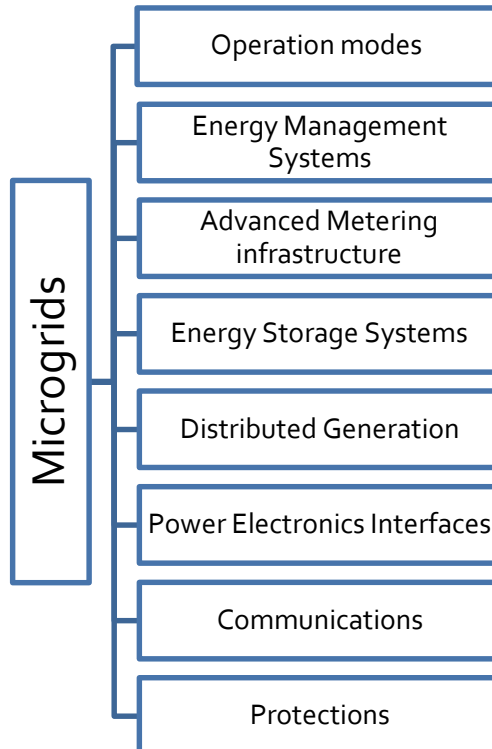


(again) it's a PI control!

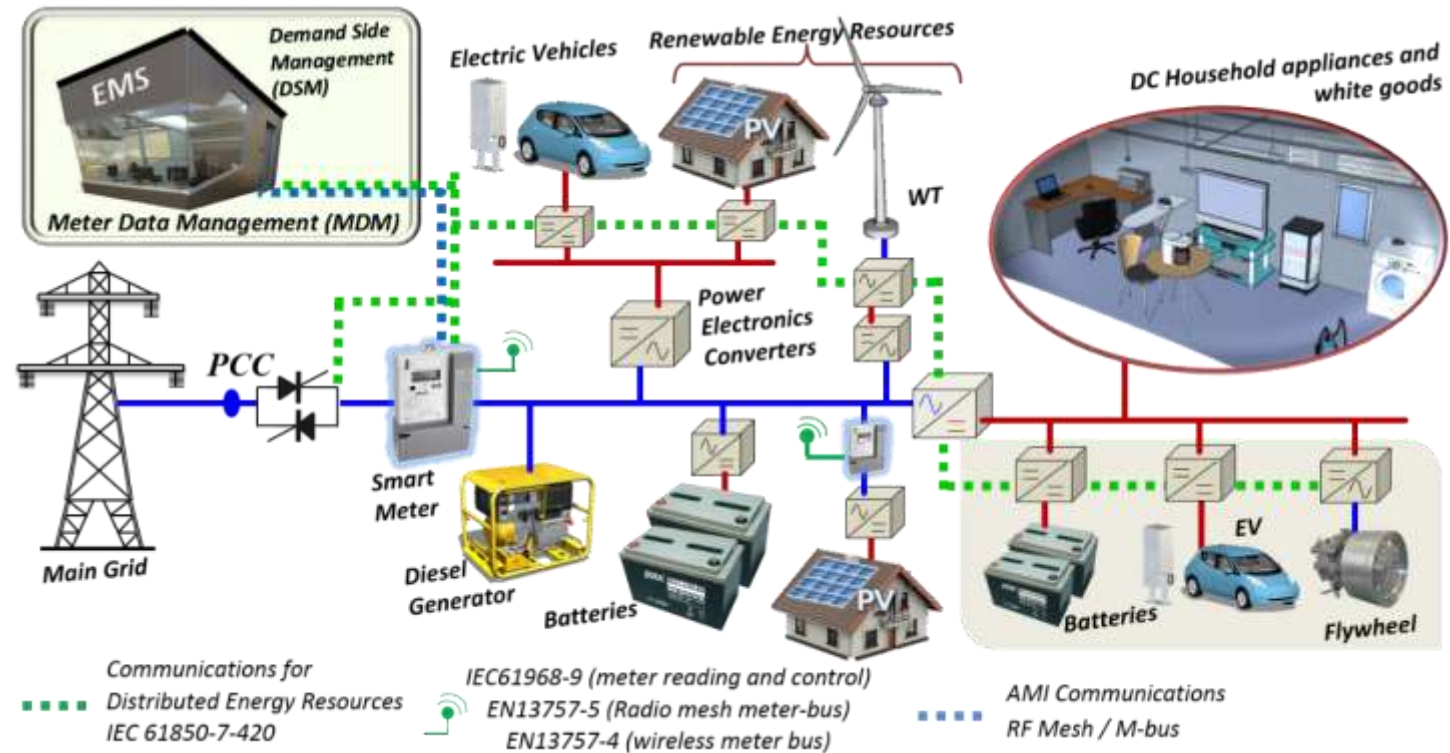


If you really want to do something, you will find the way.
Otherwise, you will find the excuse...

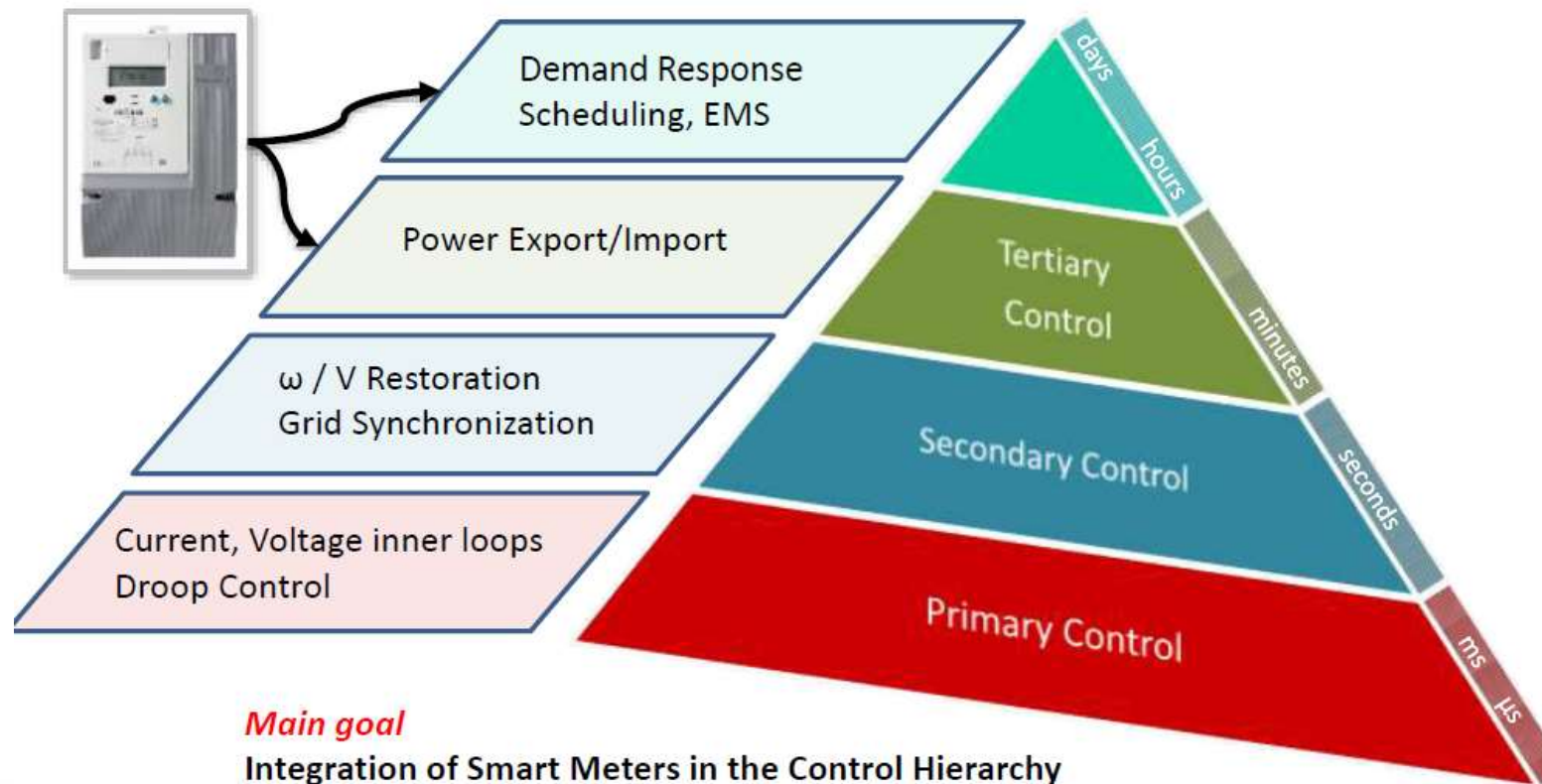
Microgrid components



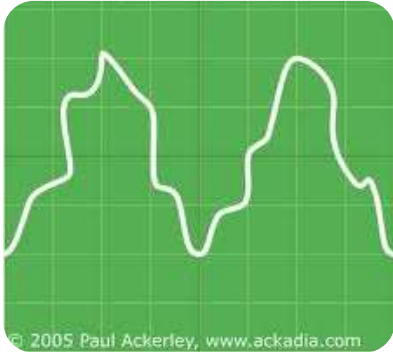
IEEE Std 1547.4



Hierarchical Control for Microgrids



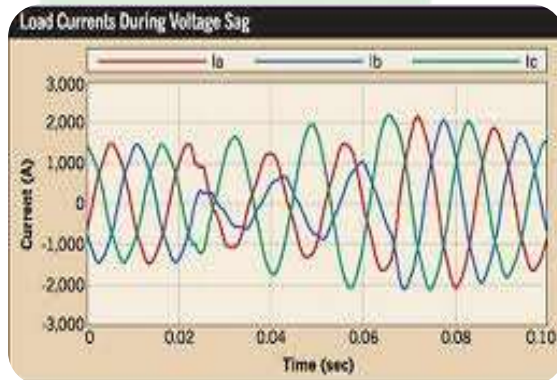
Power Quality Issues



Problem: **Harmonics in Microgrids**

Possible solutions:

- One DG unit could give more harmonics than another. (harmonic current sharing)
- Voltage Harmonic Reduction (Control strategies for HC)



Problem: **Unbalances in Microgrids**

Possible solutions:

- By means of sec. control, PCC voltage unbalances can be compensated by control signals to the primary level.
- Voltage Unbalance Compensation (Control strategies)

Test and verification that the proposed solutions follow the European power quality standards **IEC 61727 and IEC 61000-3-6.**

The Whac-a-mole effect

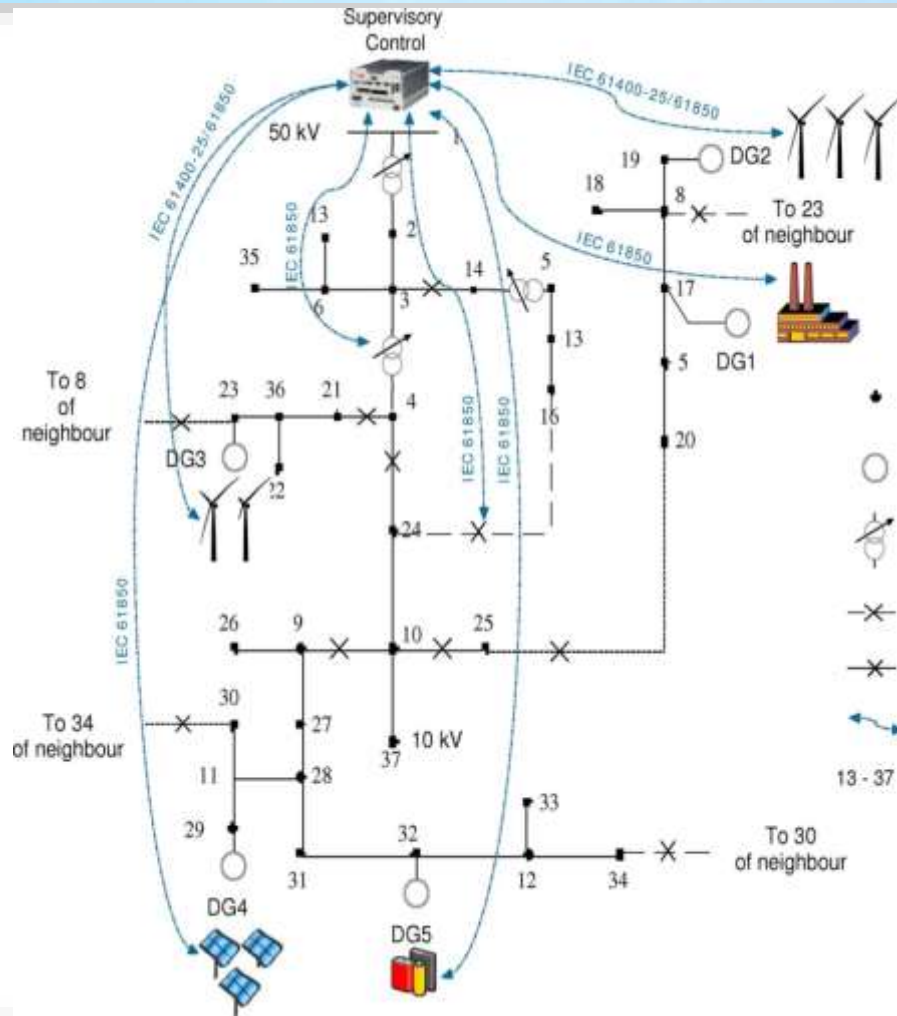
Primary control

Harmonic virtual impedance

Secondary control

Harmonic/unbalance coordination
control



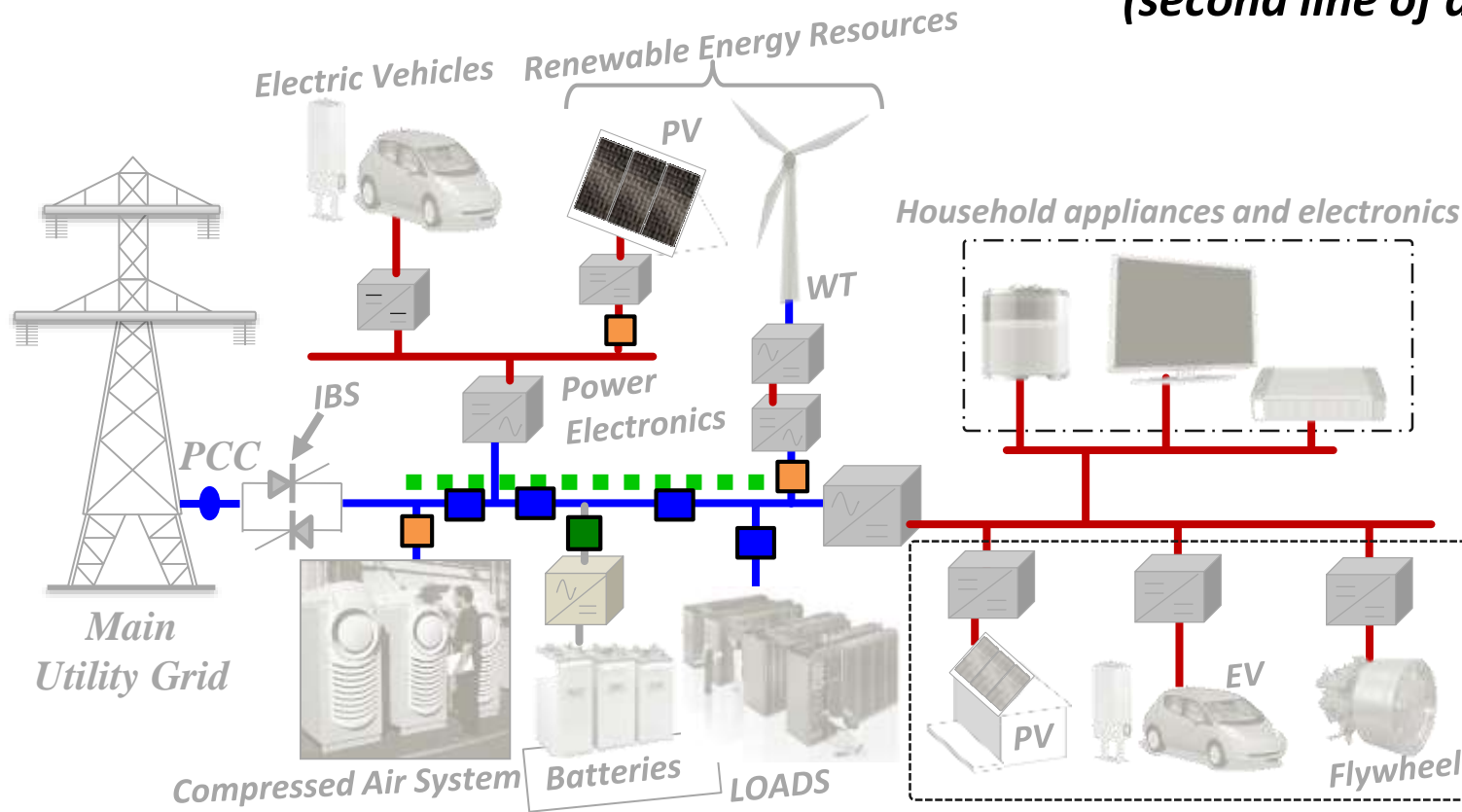


Communication model provided by **IEC 61850** & **IEC 61400-25** to describe the physical devices in the network model.

- Study meter-bus technology solutions to integrate smart meters and data concentrators according to EN13757.
- Develop different levels of communications architectures for residential AMI following IEC61968-9 (interface standard for meter reading and control).
- Integrate smart meters and data concentrators in different levels of wireless and meshed network architectures, according to **EN13757-5 (standard for radio mesh meter-bus)** and EN13757-4 (wireless meter-bus).

Protections

**Ultra Fast communication link
(second line of defense)**



Source Protection
 Network Protection
 Bidirectional Protection

IOT MICROGRID LABORATORY



AC MICROGRID LABORATORY



MARITIME MICROGRID LAB



EFFICIENSEA Project

DC MICROGRID LABORATORY



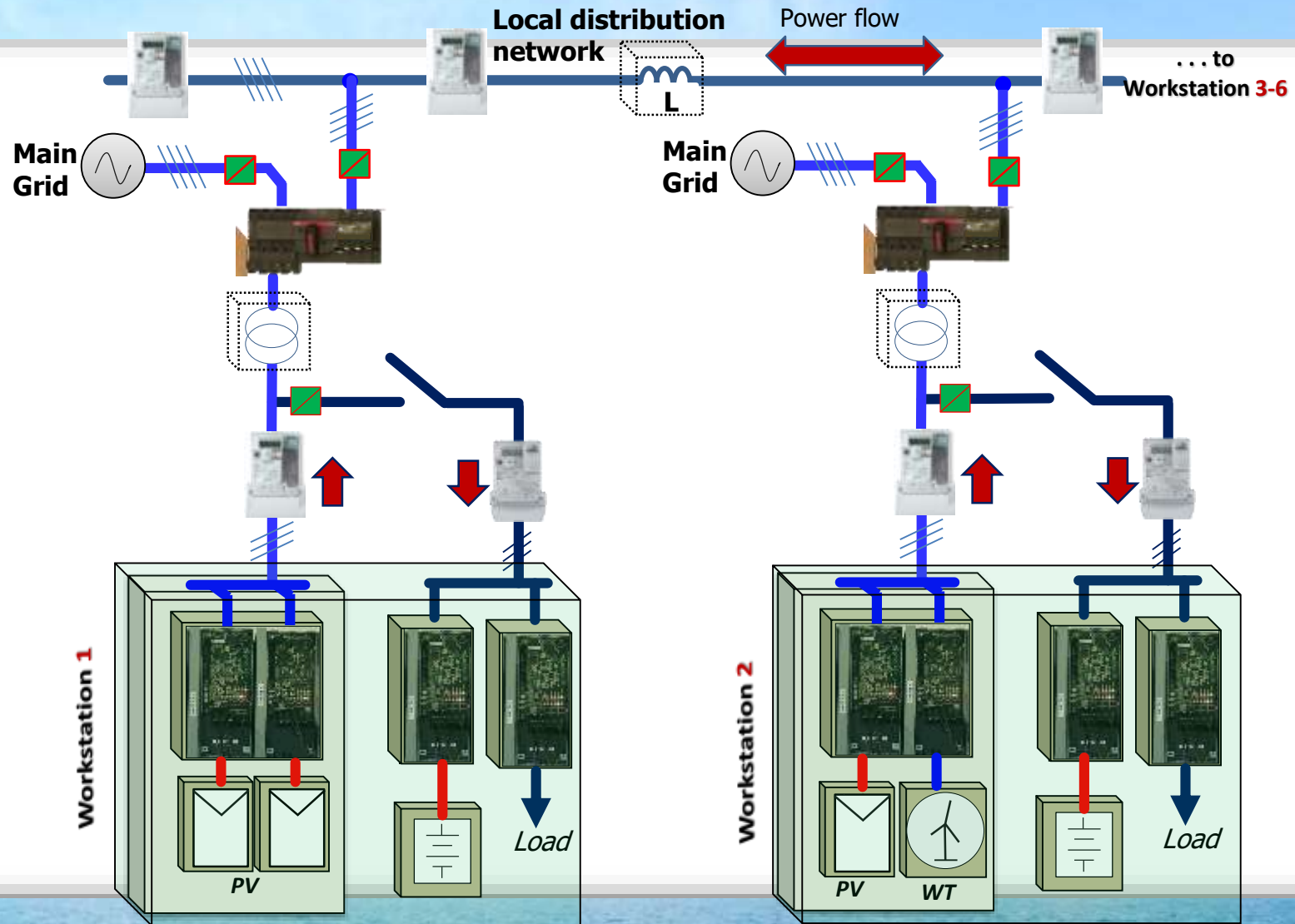
**Microgrid Research
Laboratories**



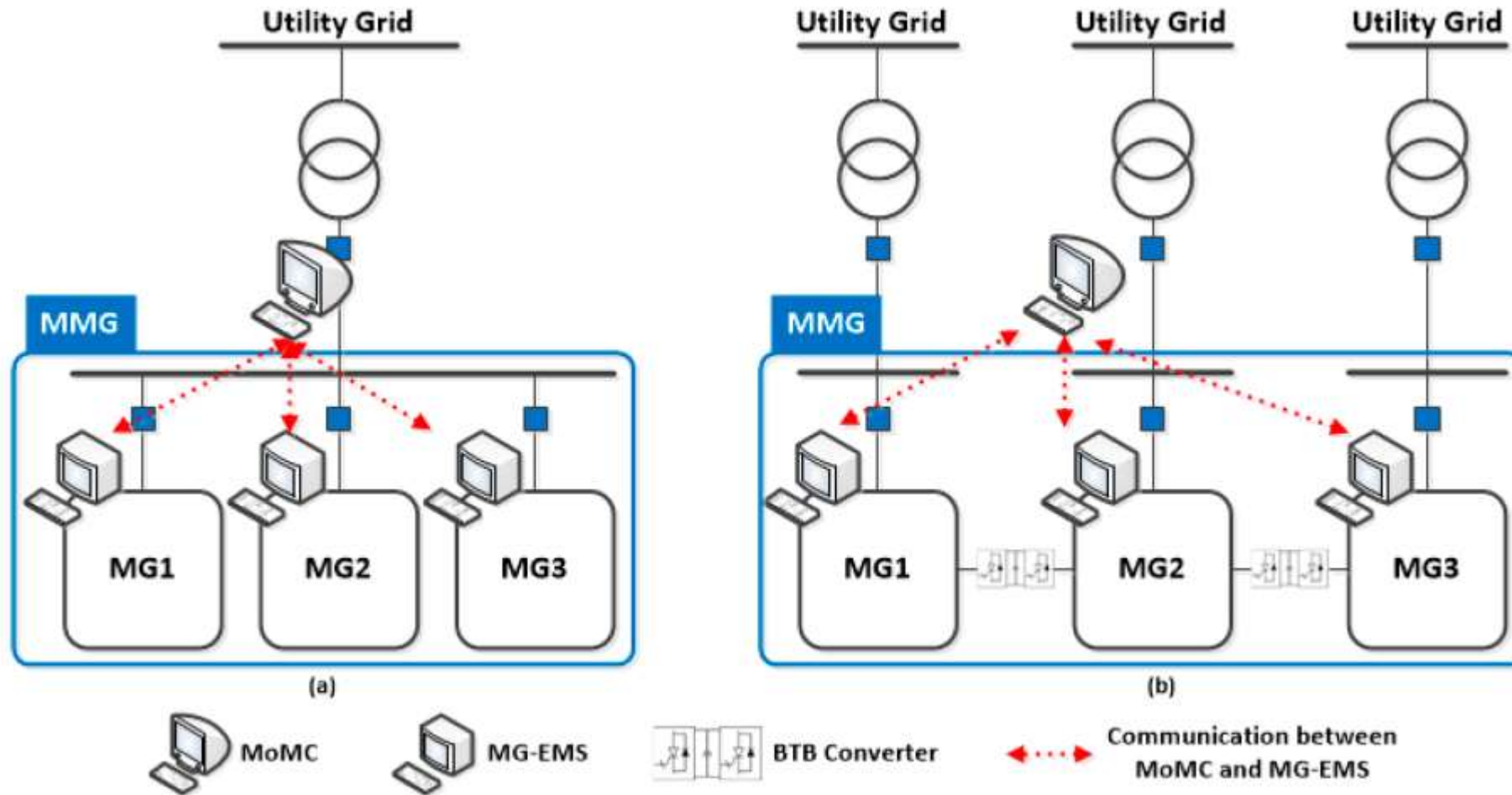




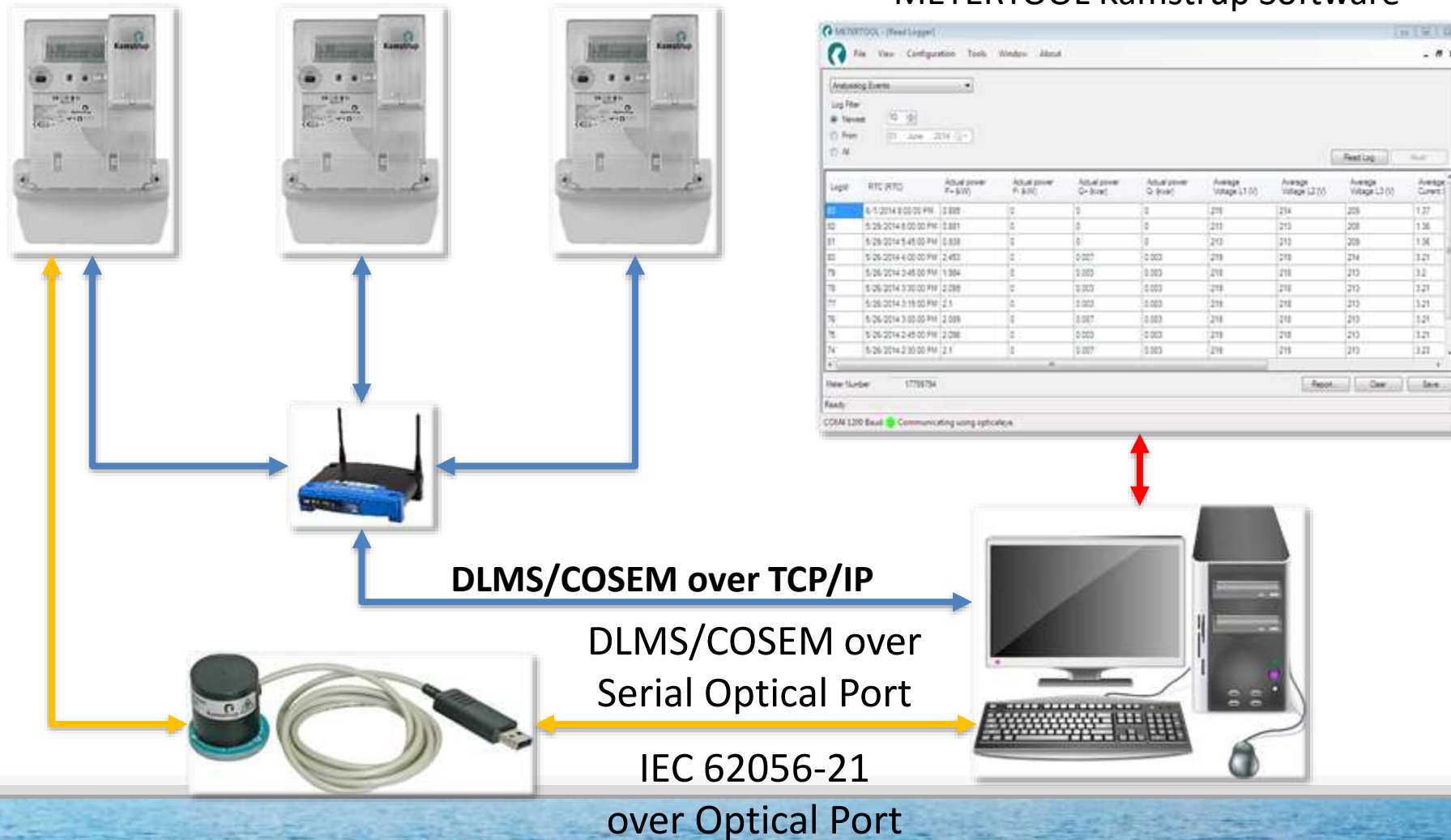
Microgrid Labs



Multi-Microgrid System



METER TOOL Kamstrup Software



METER TOOL - (Real Logger)

File View Configuration Tools Window About

Antology Events

Log Filter

▼ Teneset

From 03 June 2014

Read Log

| LogID | RTC (UTC) | Actual power P1 (kW) | Actual power P1 (kVA) | Actual power Q1 (kvar) | Actual power Q1 (kvar) | Average Voltage L1 (V) | Average Voltage L2 (V) | Average Voltage L3 (V) | Average Current |
|-------|----------------------|----------------------|-----------------------|------------------------|------------------------|------------------------|------------------------|------------------------|-----------------|
| 80 | 5/1/2014 8:00:00 PM | 2.889 | 0 | 0 | 0 | 219 | 214 | 209 | 1.27 |
| 82 | 5/26/2014 8:00:00 PM | 2.881 | 0 | 0 | 0 | 219 | 219 | 208 | 1.26 |
| 81 | 5/26/2014 8:45:00 PM | 2.938 | 0 | 0 | 0 | 219 | 219 | 209 | 1.26 |
| 83 | 5/26/2014 4:00:00 PM | 2.453 | 0 | 0.007 | 0.003 | 219 | 219 | 214 | 1.21 |
| 79 | 5/26/2014 2:45:00 PM | 1.984 | 0 | 0.003 | 0.003 | 219 | 219 | 219 | 1.2 |
| 78 | 5/26/2014 3:30:00 PM | 2.098 | 0 | 0.003 | 0.003 | 219 | 219 | 219 | 1.21 |
| 77 | 5/26/2014 3:15:00 PM | 2.5 | 0 | 0.003 | 0.003 | 219 | 219 | 219 | 1.21 |
| 76 | 5/26/2014 3:00:00 PM | 2.099 | 0 | 0.007 | 0.003 | 219 | 219 | 219 | 1.21 |
| 75 | 5/26/2014 2:45:00 PM | 2.088 | 0 | 0.003 | 0.003 | 219 | 219 | 219 | 1.21 |
| 74 | 5/26/2014 2:30:00 PM | 2.1 | 0 | 0.007 | 0.003 | 219 | 219 | 219 | 1.21 |

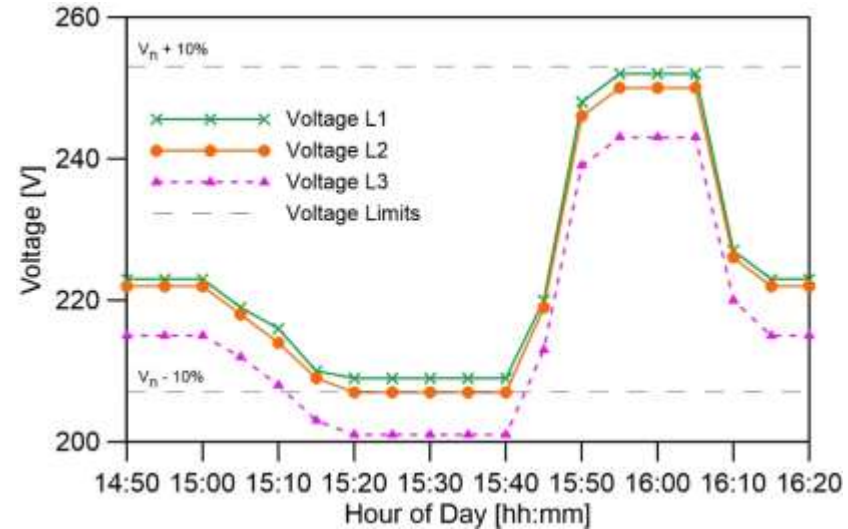
Row Number: 17798704

Ready: COM4 1200 Baud Communicating using optocoupler

Report Clear Save

Example: Voltage Quality Events Detection

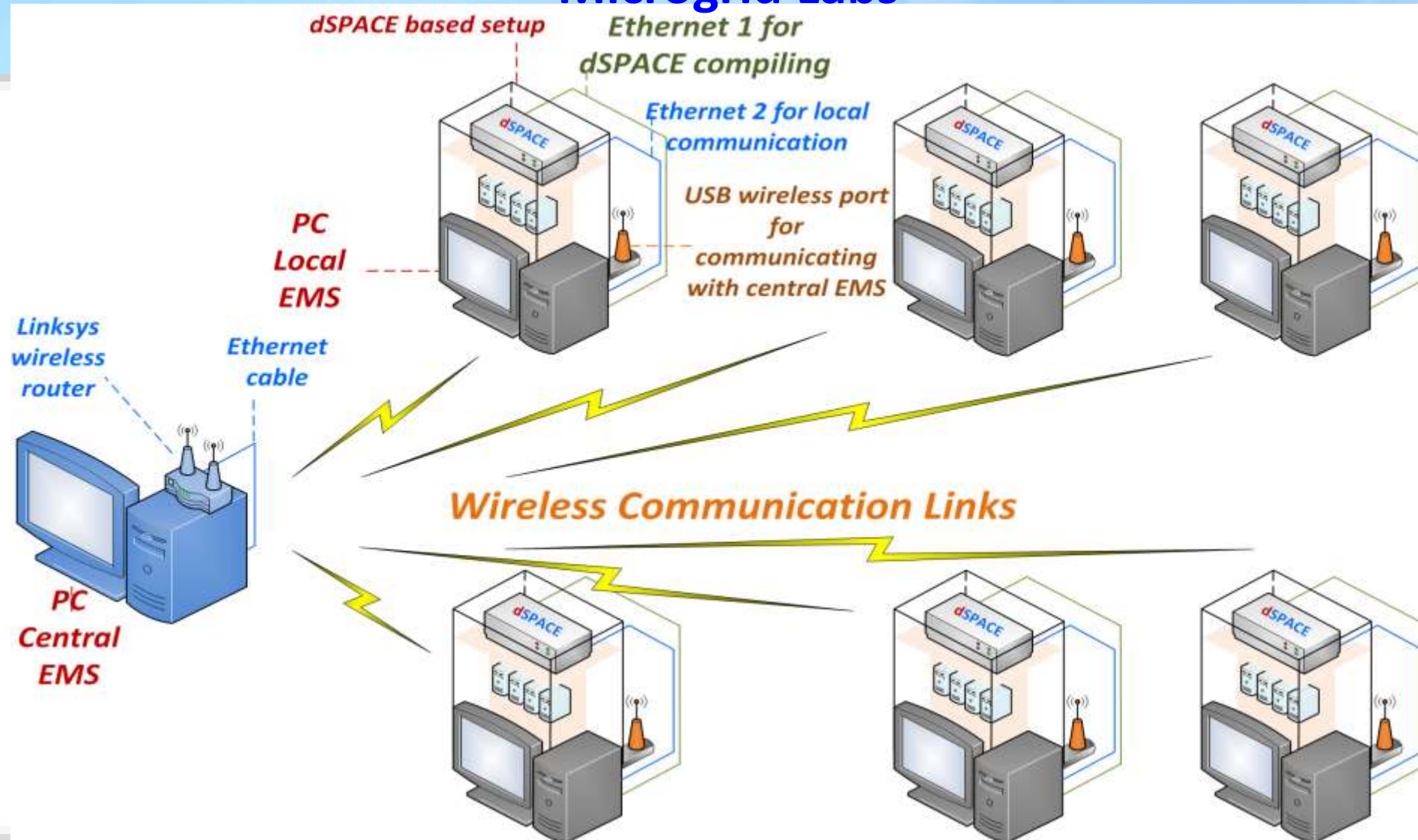
- Three-phase voltages
- 5 minutes resolution
- $\pm 10\%$ Voltage tolerance



- 2 Events detected:
 - Under voltage at 15:12:14
 - Voltage restoration at 15:41:51

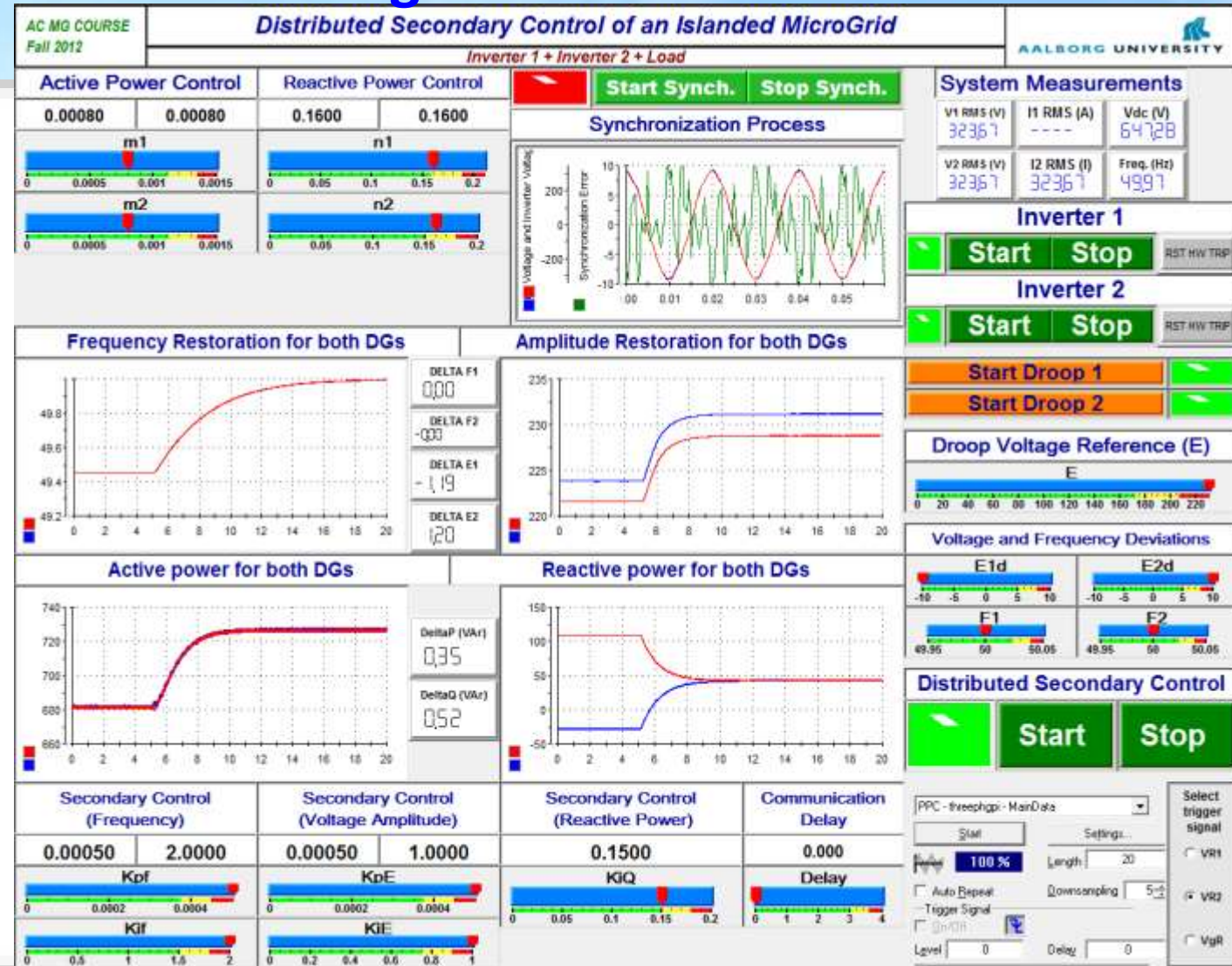
| RTC (RTC) | Hour counter (h) | Voltage extremity (V) | Voltage event |
|---------------------|------------------|-----------------------|---|
| 5/5/2015 1:28:42 PM | 66 | 0 | System L1,L2,L3: Power enabled - above cutoff threshold |
| 5/5/2015 3:12:14 PM | 68 | 0 | System L3: Voltage below limits |
| 5/5/2015 3:41:51 PM | 68 | 91 | System L3: Voltage within limits from minimum |
| 5/5/2015 4:19:25 PM | 69 | 0 | System L1,L2,L3: Power cut off |

Microgrid Labs

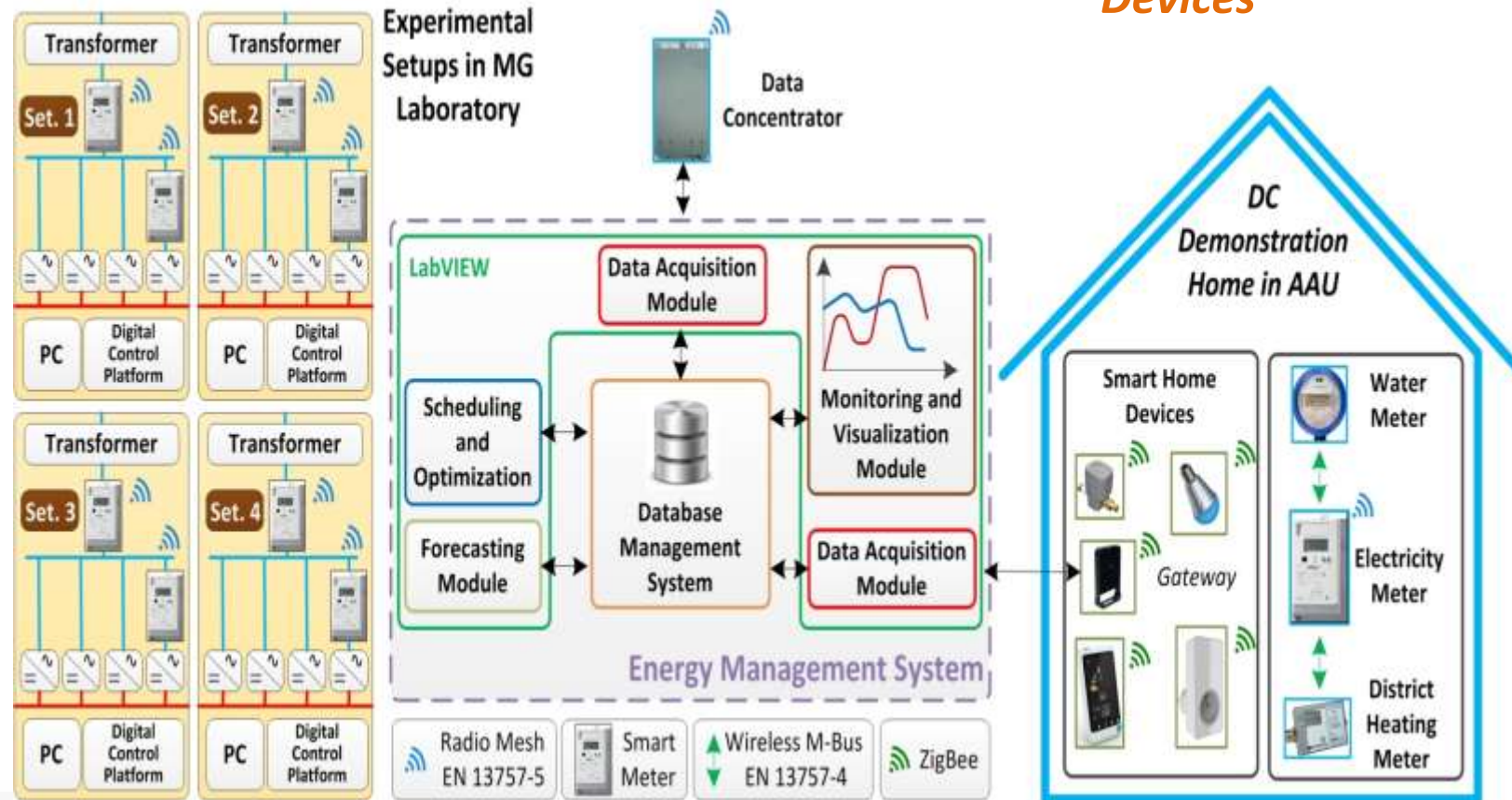


Real-time control and monitoring platform through *Control-Desk*

Control schemes from Matlab/Simulink library are directly compiled into C code and downloaded to the dSPACE



Integration of Advanced Metering Infrastructure and Smart Devices



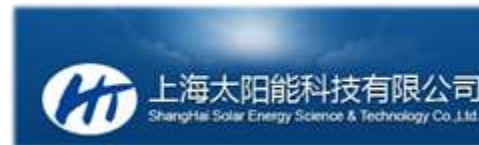
The IoT Microgrid Laboratory





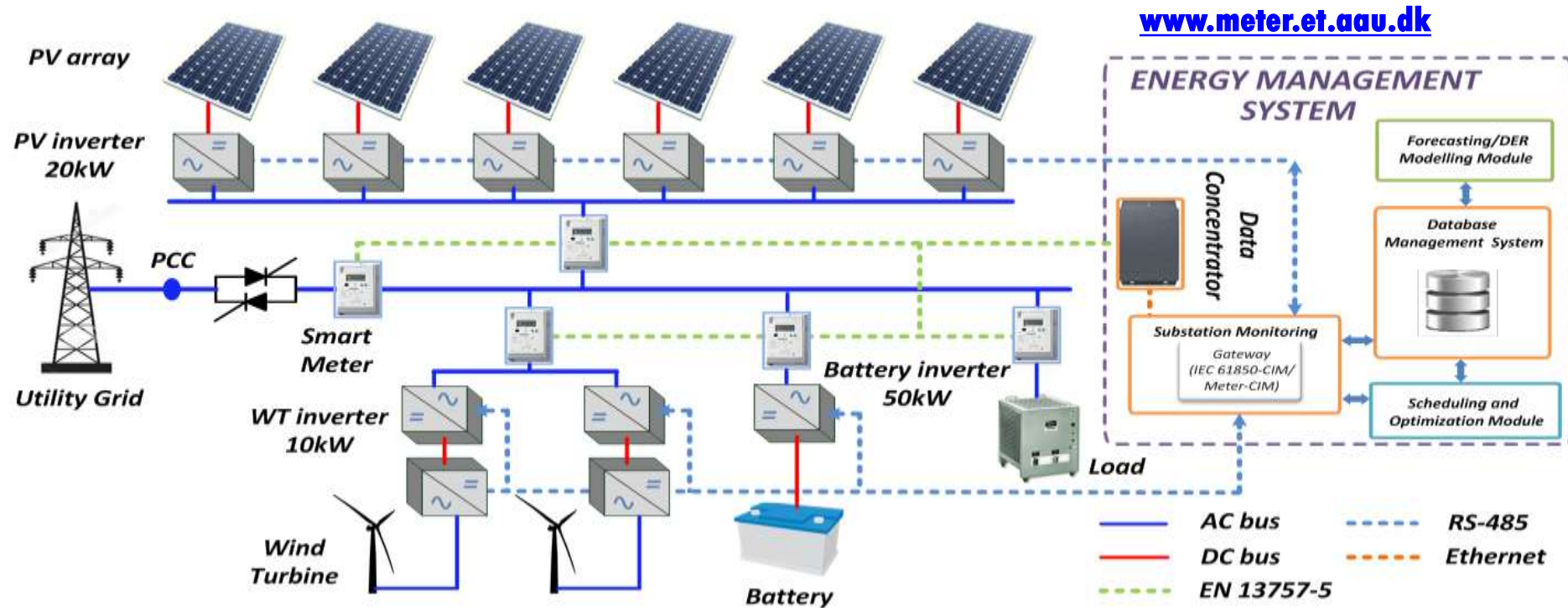
EUDP Chinese-Danish Cooperation Project

*Microgrid Technology
Research and Demonstration
2014 - 2017*



- Microgrid technology research based on wind/PV/storage hybrid system – HyMG

A 200 kW hybrid PV-wind-battery microgrid site built and tested in **Shanghai**.



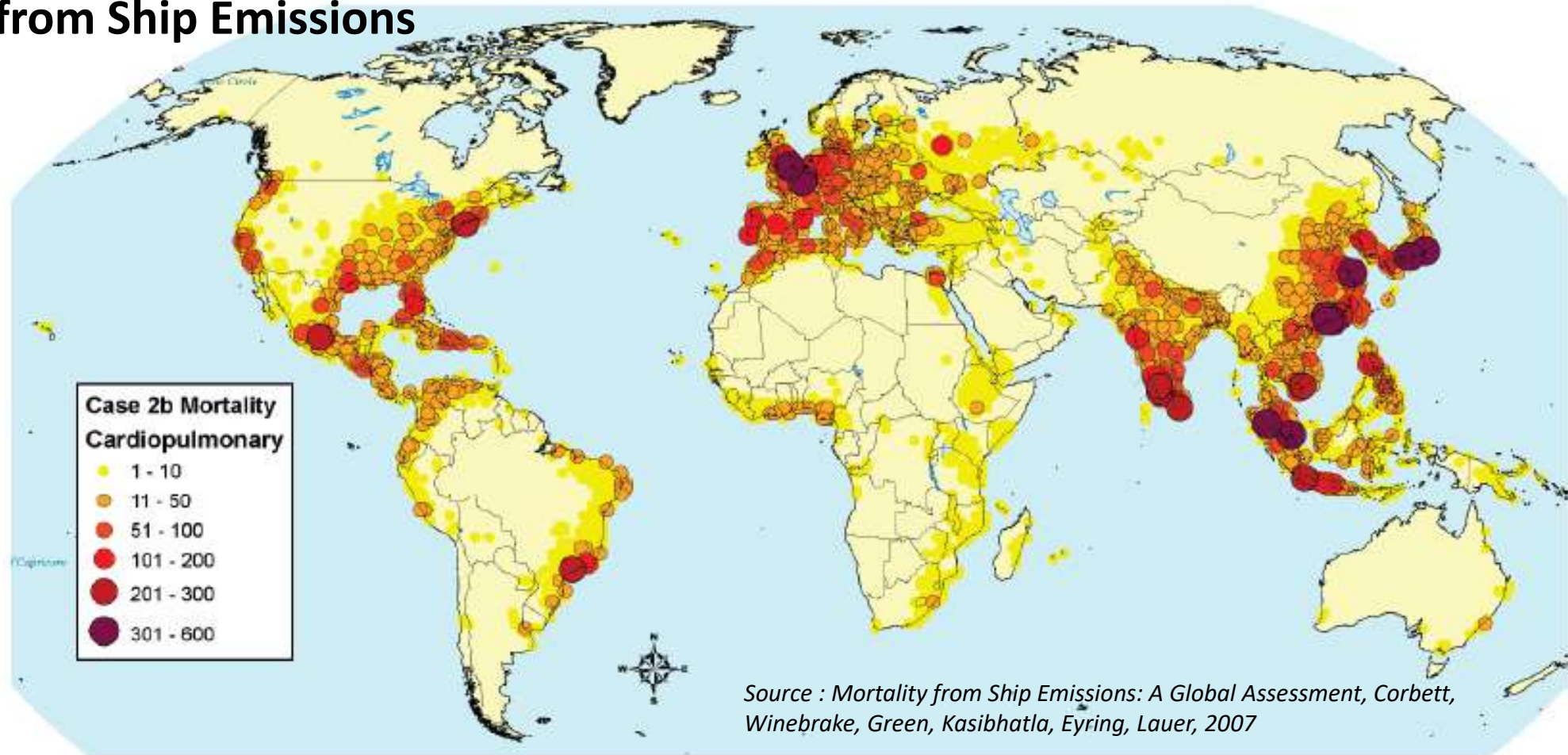
A. Luna, et al, "Optimal Power Scheduling for a Grid-Connected Hybrid PV-Wind-Battery Microgrid System", APEC 2016



- State-of-the-art and trends in SPS
- AC-DC grids in SPS
- ESS integration
- Power Quality Issues in SPS
- Cold-Ironing

- State-of-the-art and trends in SPS**
- AC-DC grids in SPS
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Mortality from Ship Emissions



2%

... of global CO₂ emissions

15%

... of global nitrogen oxide (NO_x) emissions**

6%

... of global sulfur oxide (SO_x) emissions**

... are generated by ships

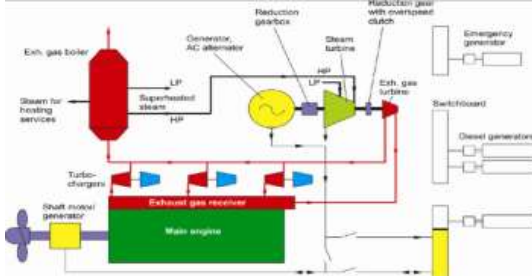
Several methods for improving fuel efficiency



LNG



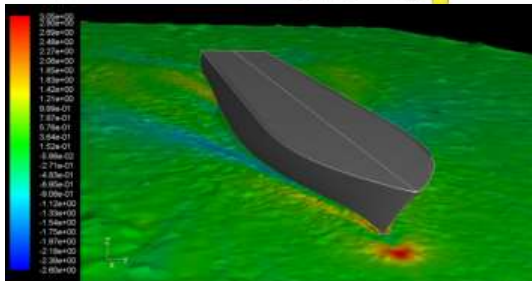
ECO upgrades



Waste
Heat
recovery



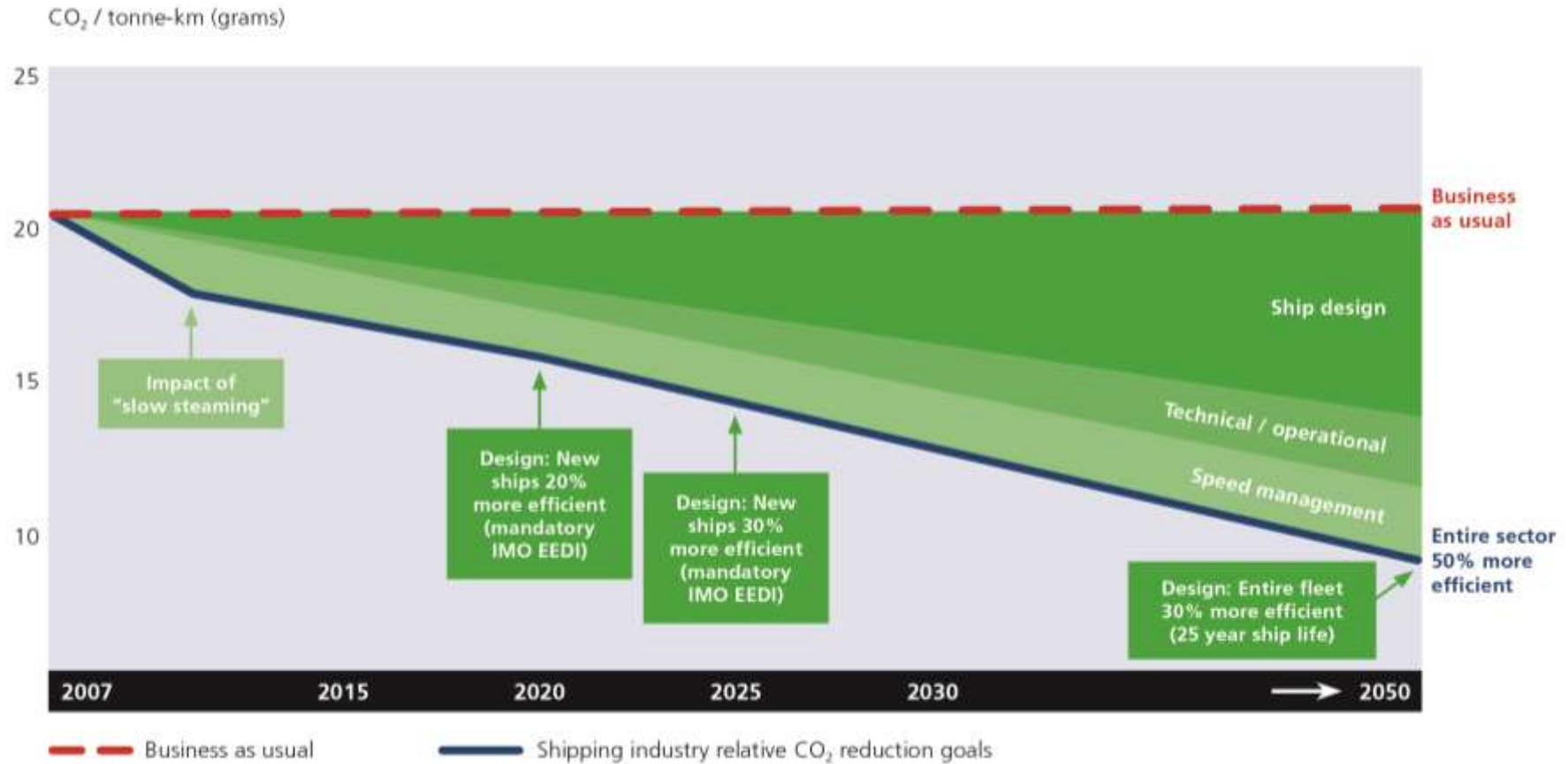
Port-to-ship
Shore
connection



Hull
optimisation

Source: Schneider Electric

Shipping's CO₂ Reduction Goals

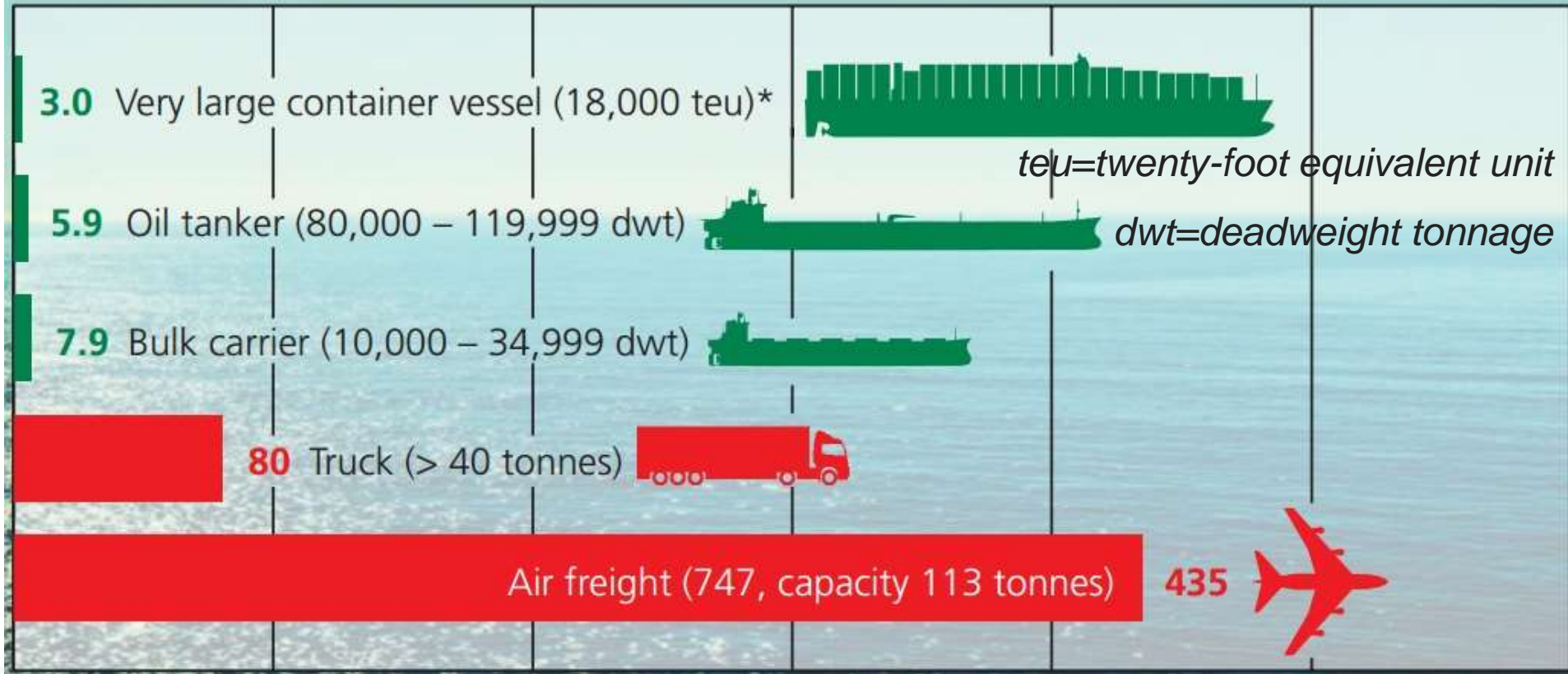


Source : ICS

Comparison of CO₂ emissions between modes of transport

Grams per tonne/km

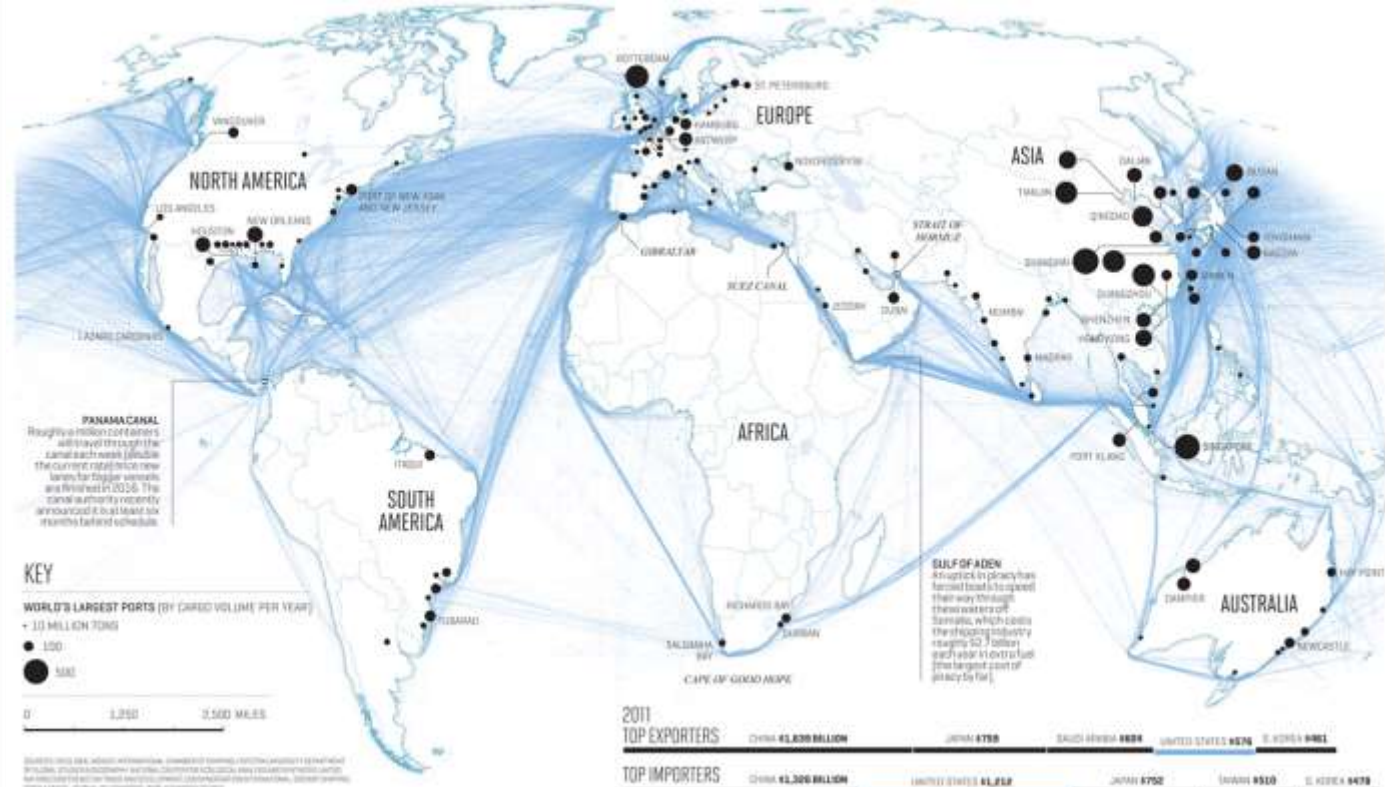
Source: Second IMO GHG Study (*AP Møller-Maersk, 2014)



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



53'
48'
45'
40'
20'



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



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

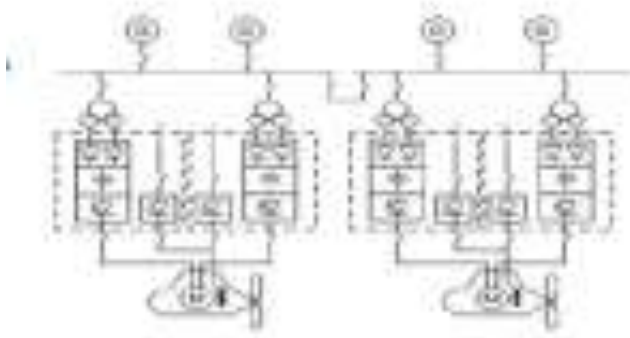


The biggest in the world:

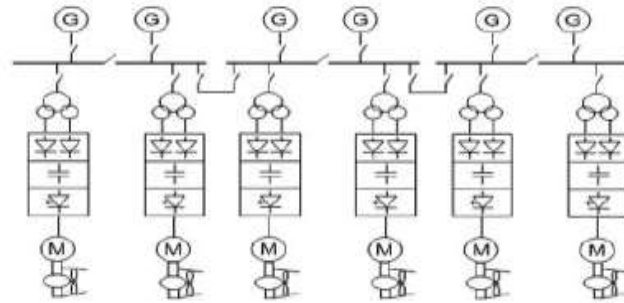
- 2,000 metric-ton fully-electric
- 70.5m long, 13.9m wide, 4.5m deep, 3.3m draft design
- Launched late 2017 in Guangzhou
- Guangzhou Shipyard International Company Ltd.
- 70.5-meter cargo boat
- Lithium battery
- Cruise for 80 kilometers
- 2h charge @ 2.4 MWh
- Top speed is 12.8 km/h



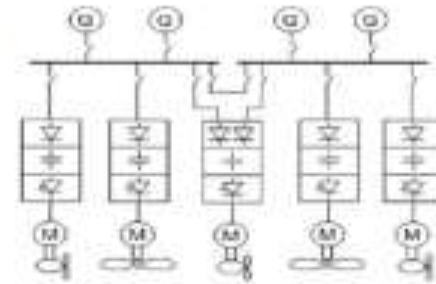
- The electric propulsion solutions applied for some of the main vessel types.
- Based on the difference requirement of the ship mission.



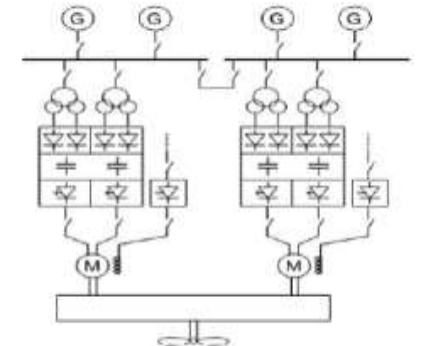
Cruise vessel



Drillship



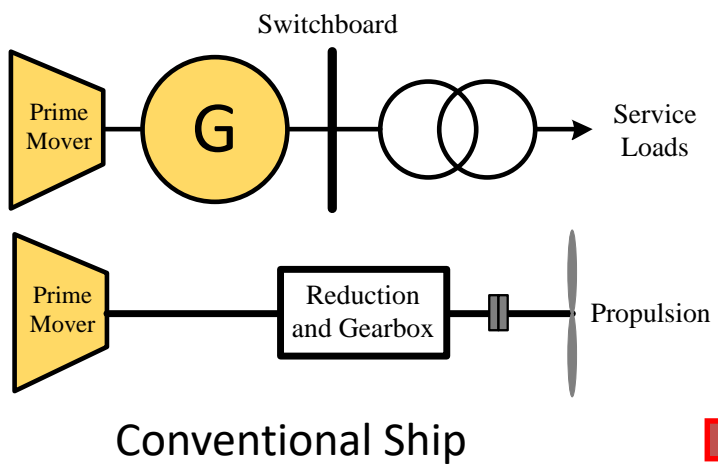
Offshore support/construction
vessels



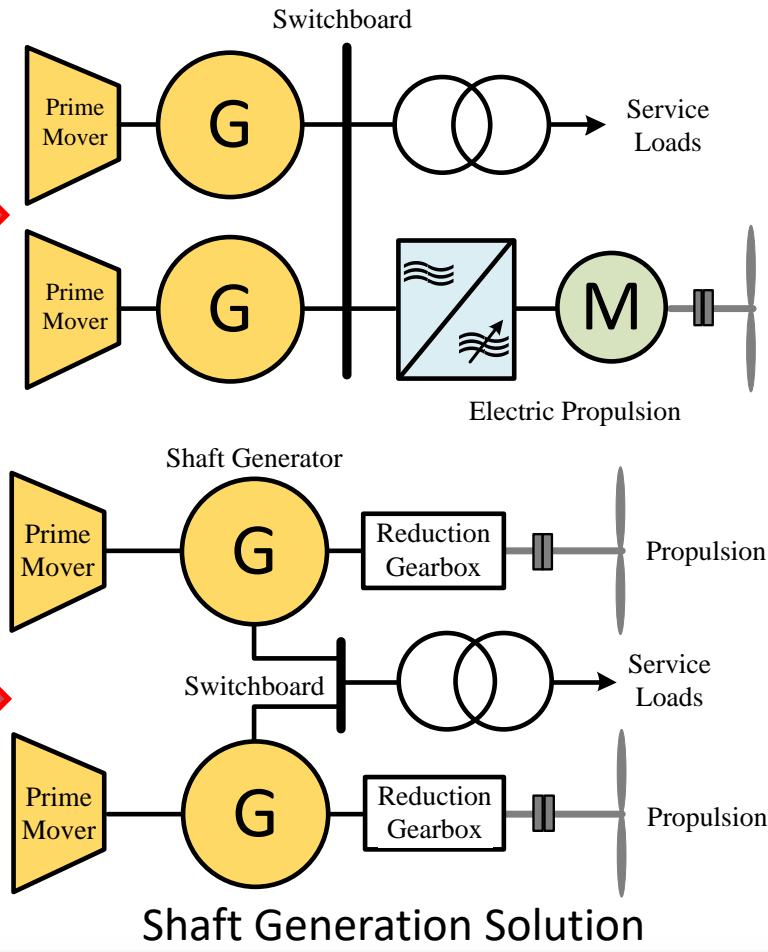
LNG Carrier

State-of-the-art of SPS

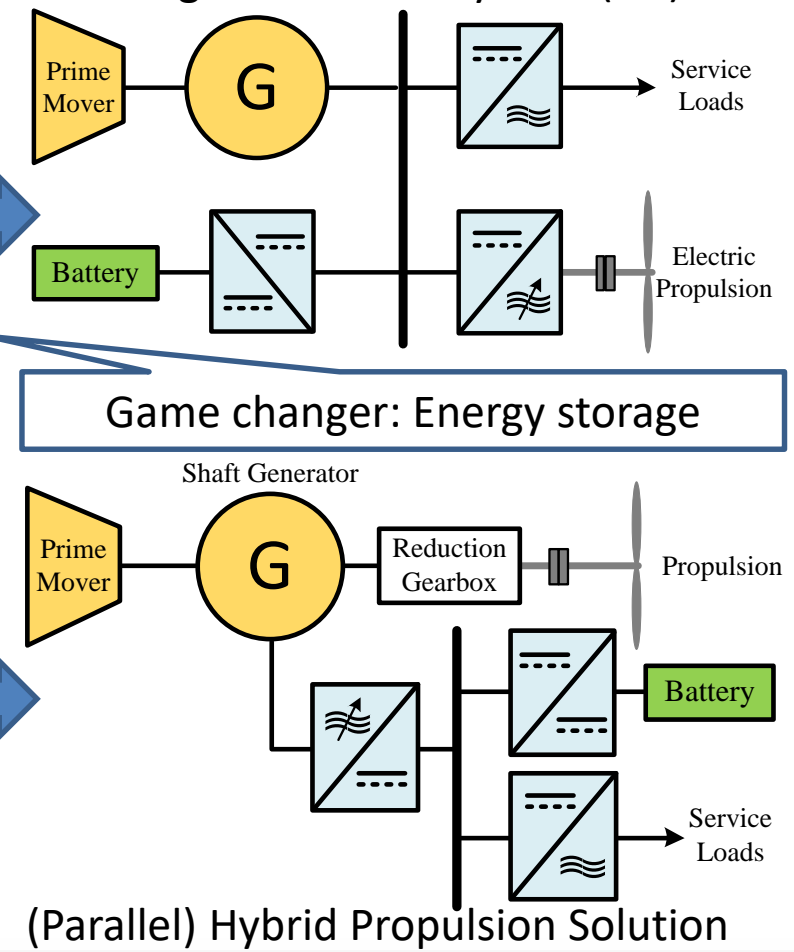
Game changer:
Growing demand of electricity



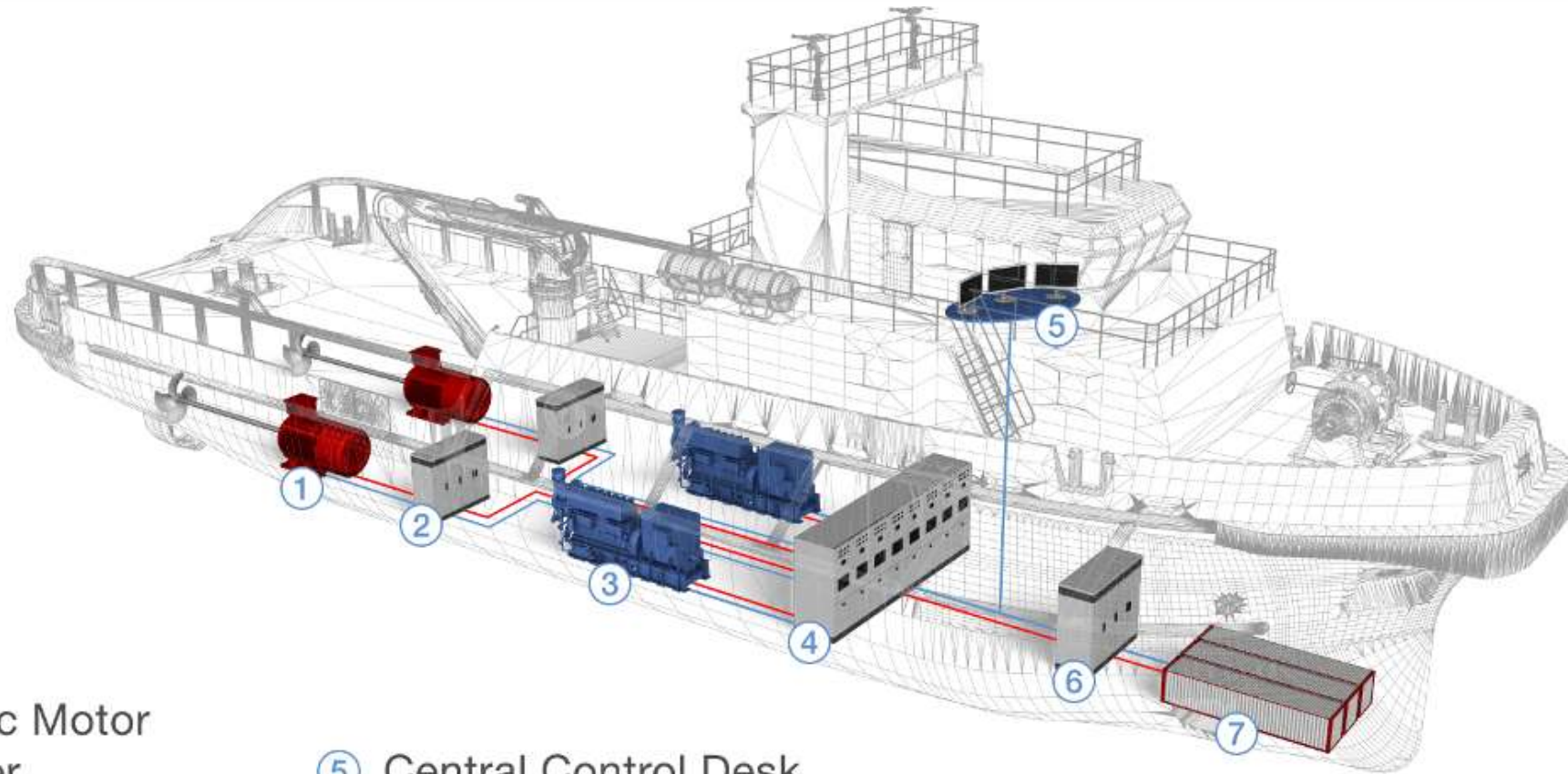
Integrated Power System (AC)



Integrated Power System (DC)



Game changer: Energy storage



- ① Electric Motor
- ② Inverter
- ③ Engine-generator
- ④ Switchgear

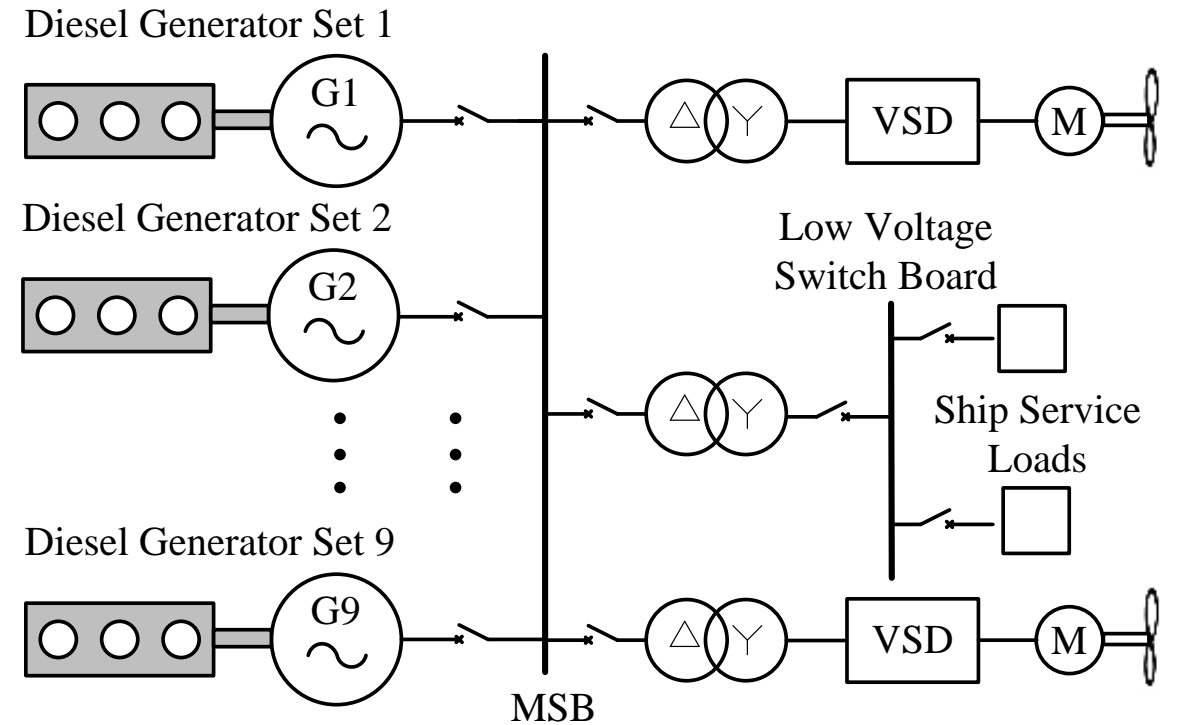
- ⑤ Central Control Desk
- ⑥ Battery Converter
- ⑦ Battery Storage

Source: Typhoon HIL

Queen Elizabeth II – cruise ship



Integrated electric propulsion configuration



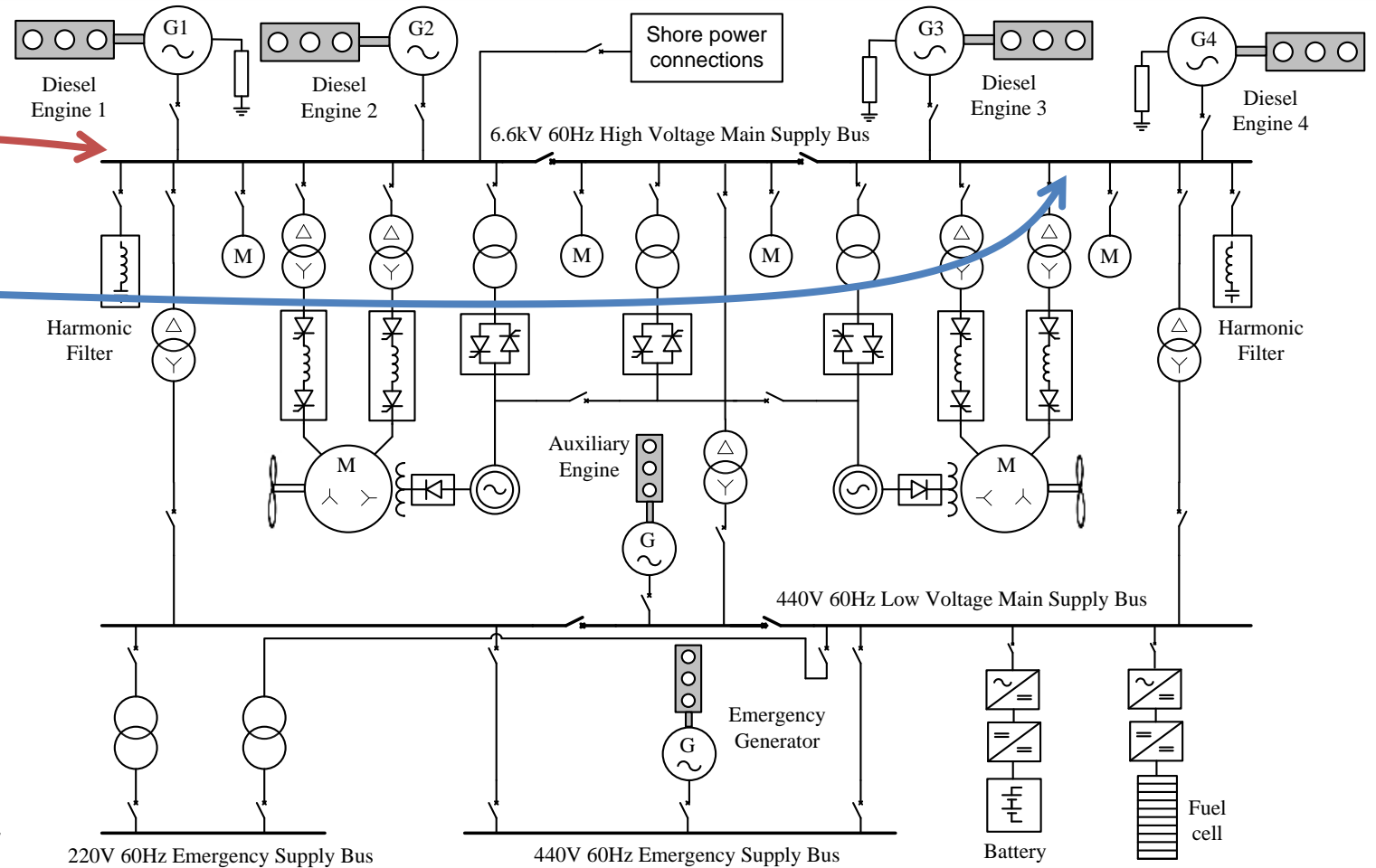
16-cylinder Wärtsilä 16V46CR EnviroEngine marine diesel engines, providing 67,200 kW (90,100 hp)@514 rpm
 2 General Electric LM2500+ gas turbines, total provide 50,000 kW (67,000 hp)

Radial AC distribution system

The 2 busses:

- port side bus
 - starboard side bus
- are linked with bus-tie switches.

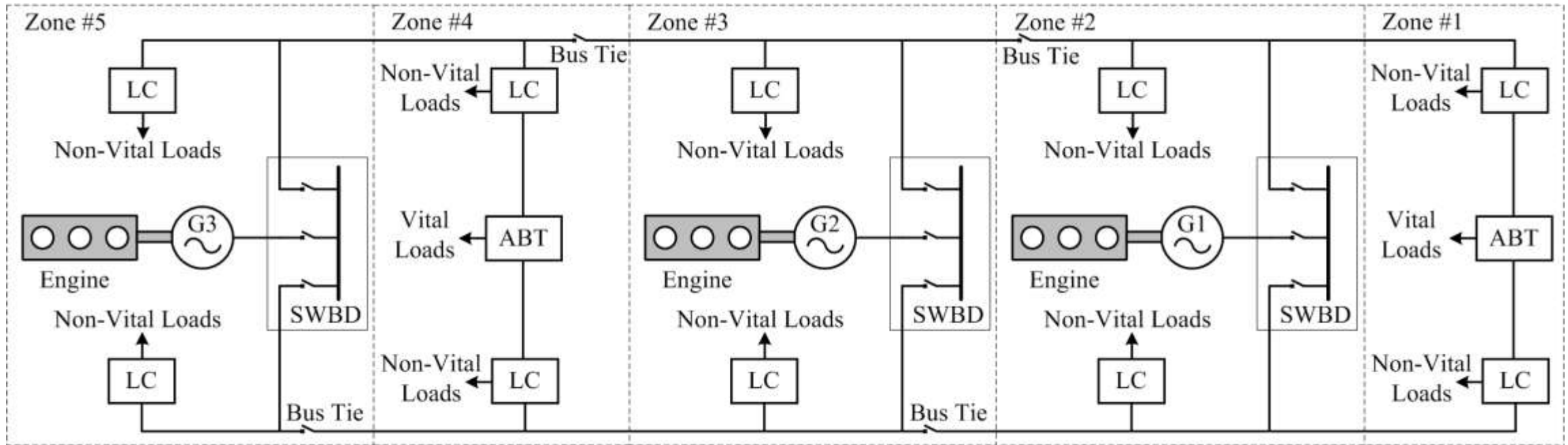
These switches can be opened to disconnect the faulty bus from the healthy bus in the event of a fault and thus potential blackouts can be prevented



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 Knowledge*, 3rd ed.; Witherby Seamanship: Livingston, UK, 2014.

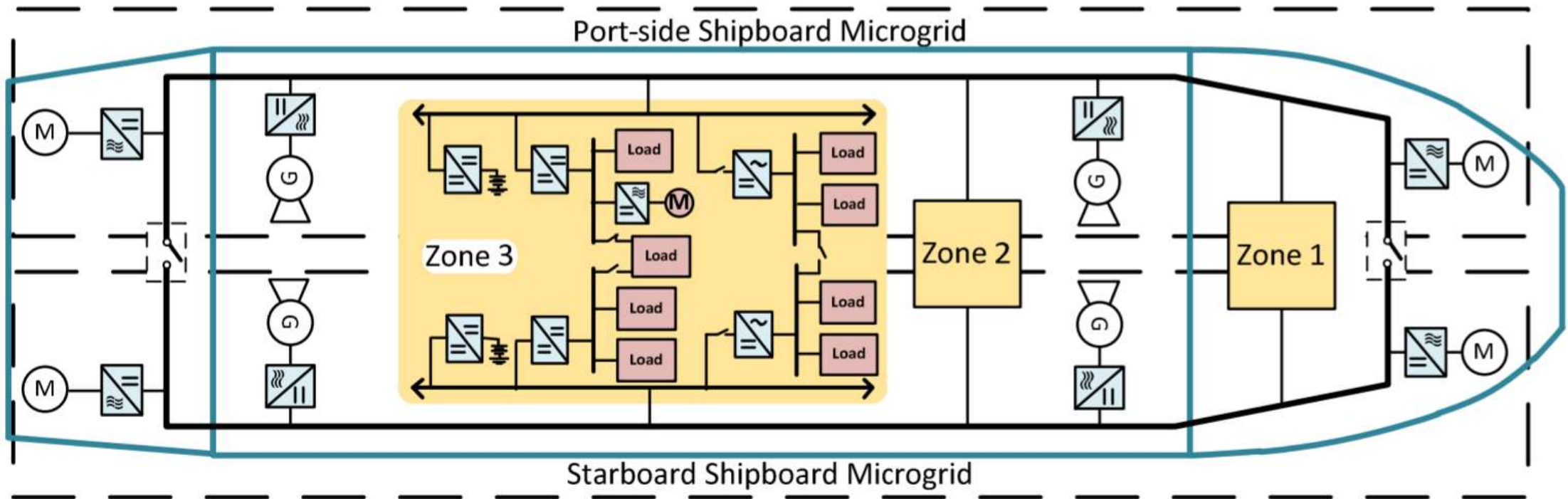
Notional AC zonal electrical distribution system / IEEE Std 45.3-2015



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

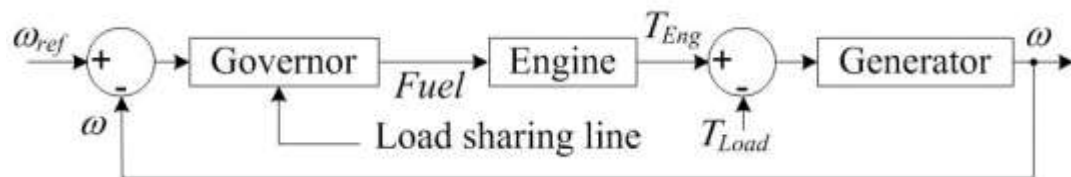
Multi-microgrids electrical propulsion ships



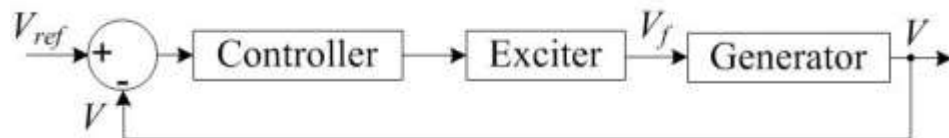
Isynchronous Control

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

Isynchronous speed controller



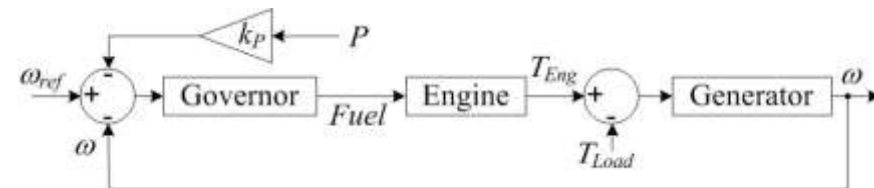
Automatic voltage regulator



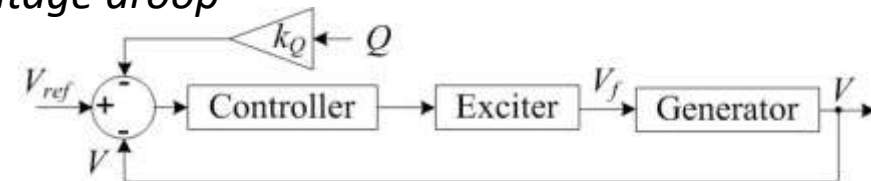
Droop Control

- 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

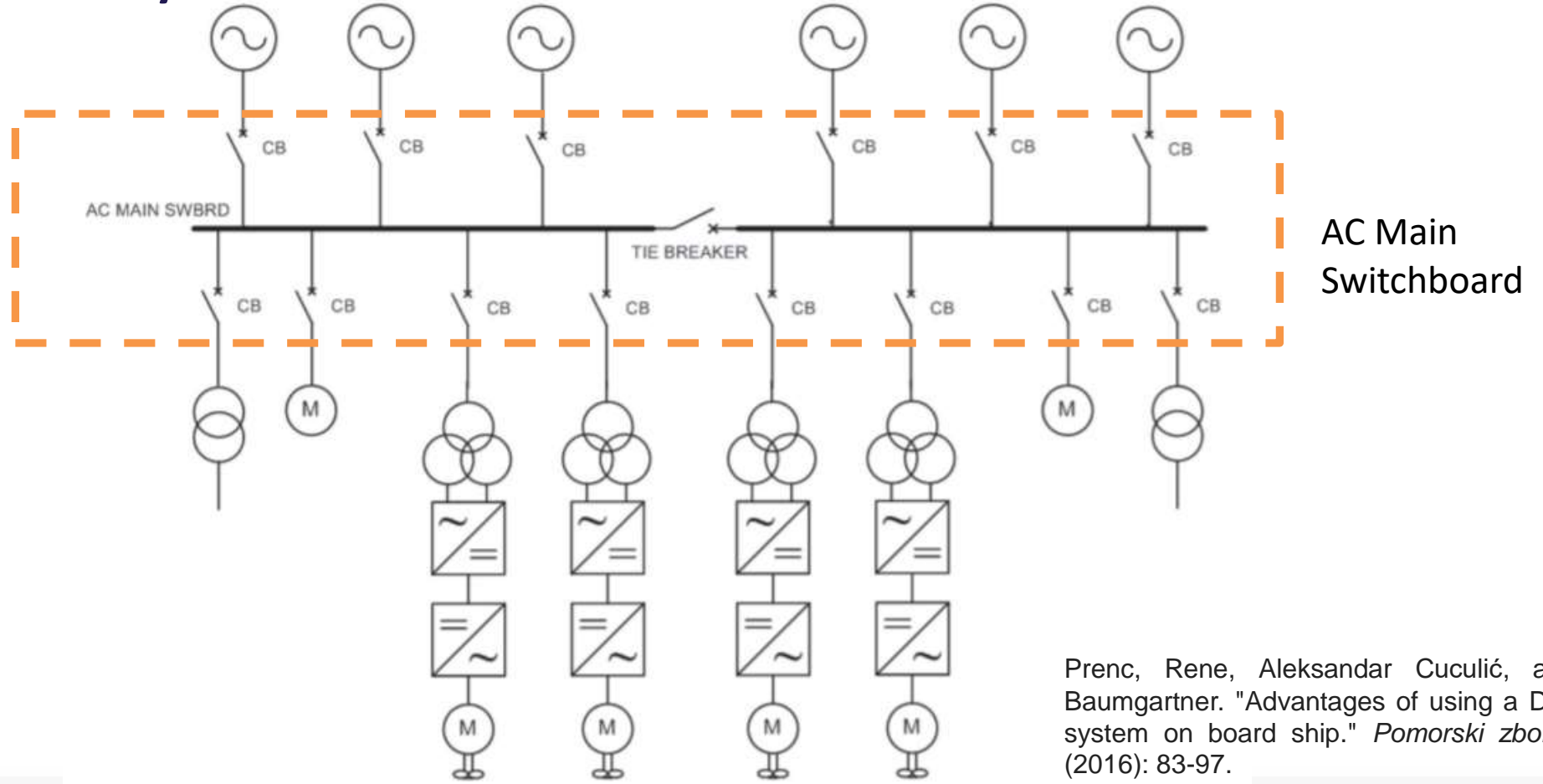


Power Management System / PMS

Functions:

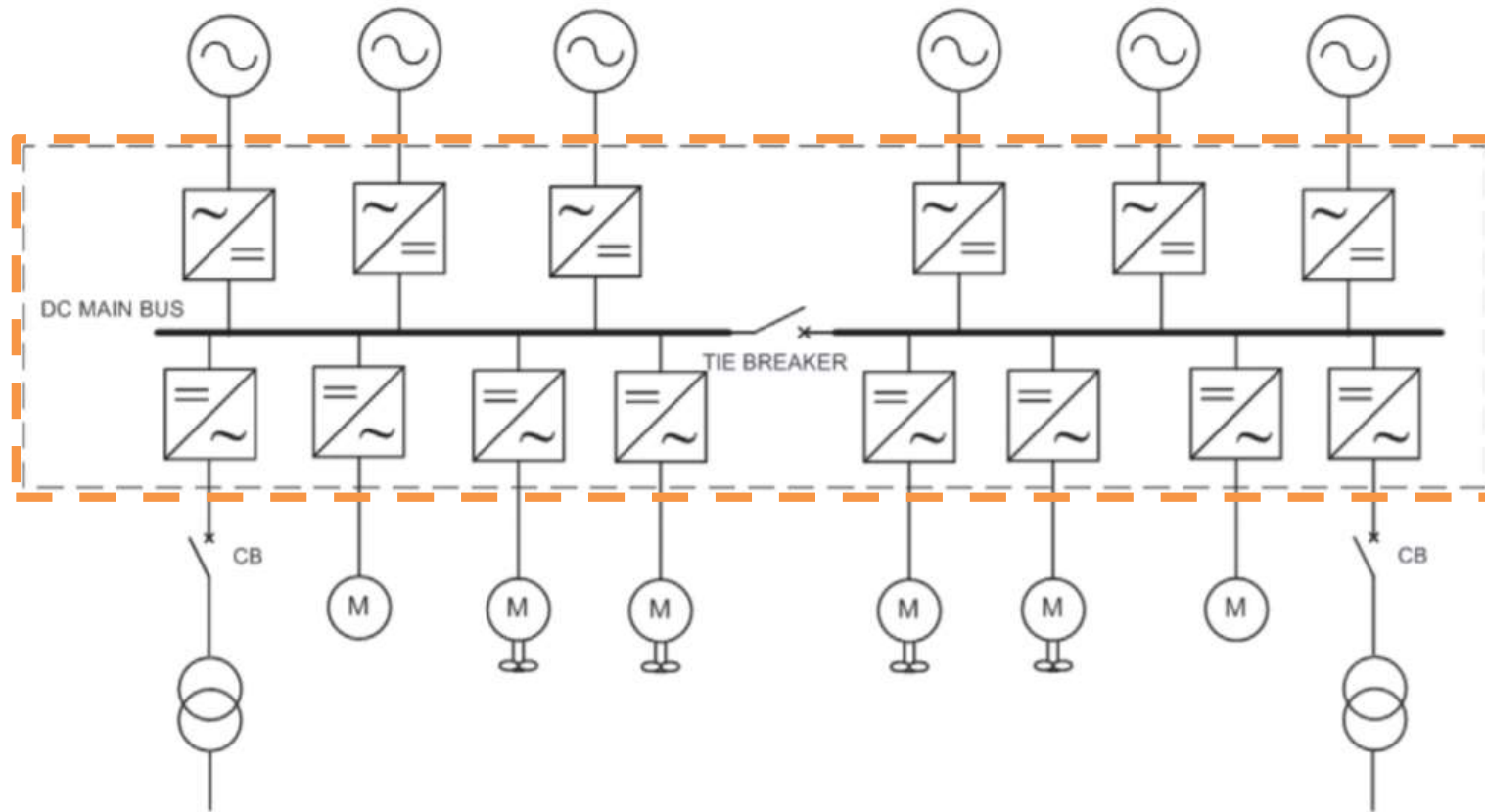
- **Energy saving:**
 - reduction in specific fuel oil consumption (SFOC)
 - reduction in propulsion fuel consumption
 - reduction in overall vessel fuel consumption.
- **Automatic start/stop/standby of auxiliary generators**
- **Automatic load sharing**
- **Load shedding**
- **Automatic synchronizing 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



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

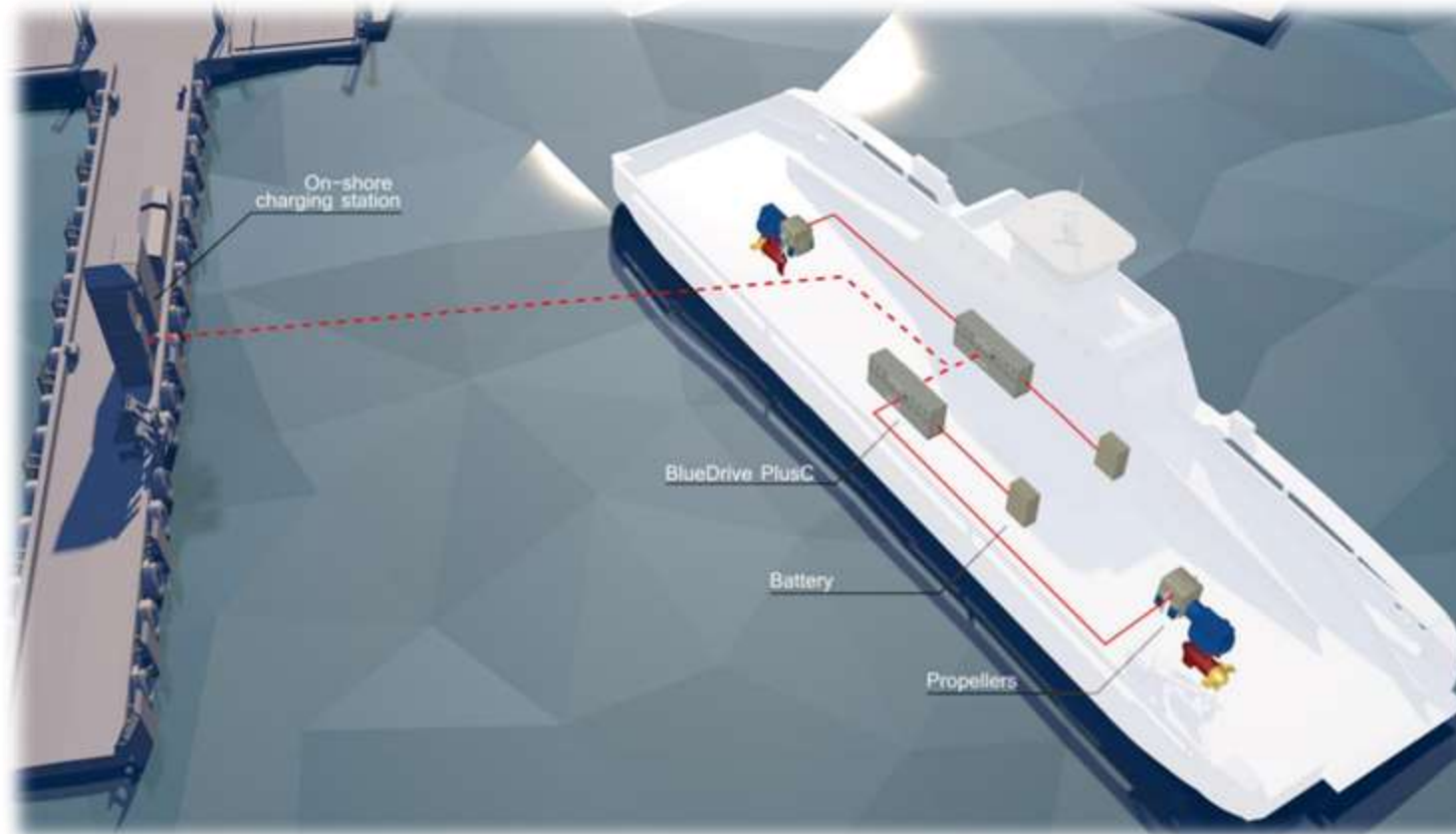
Onboard DC grid – Multidrive power system scheme



BlueDrive PlusC
from SIEMENS

<20MW

Onboard DC grid – Multidrive power system scheme



Source: SIEMENS

Onboard DC grid – Distributed power system scheme

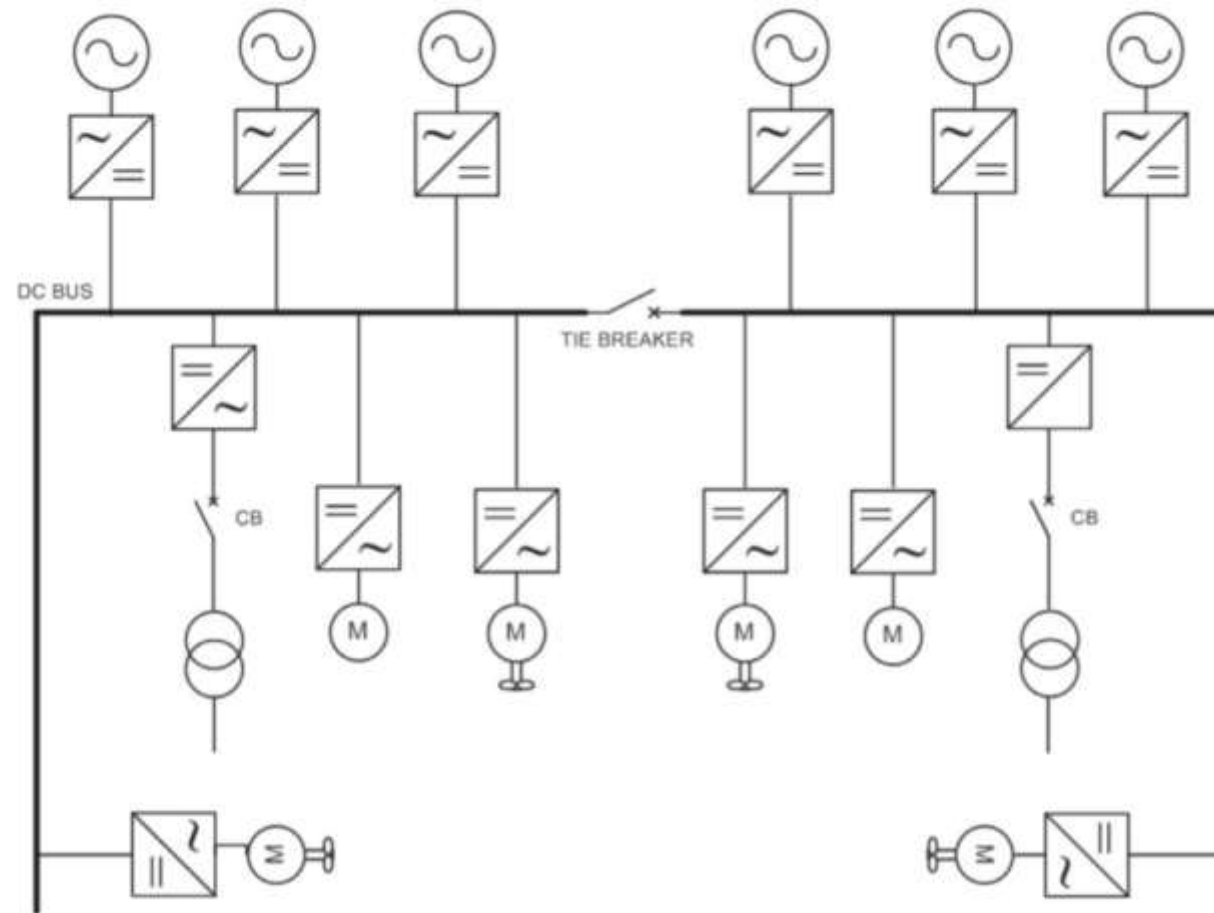
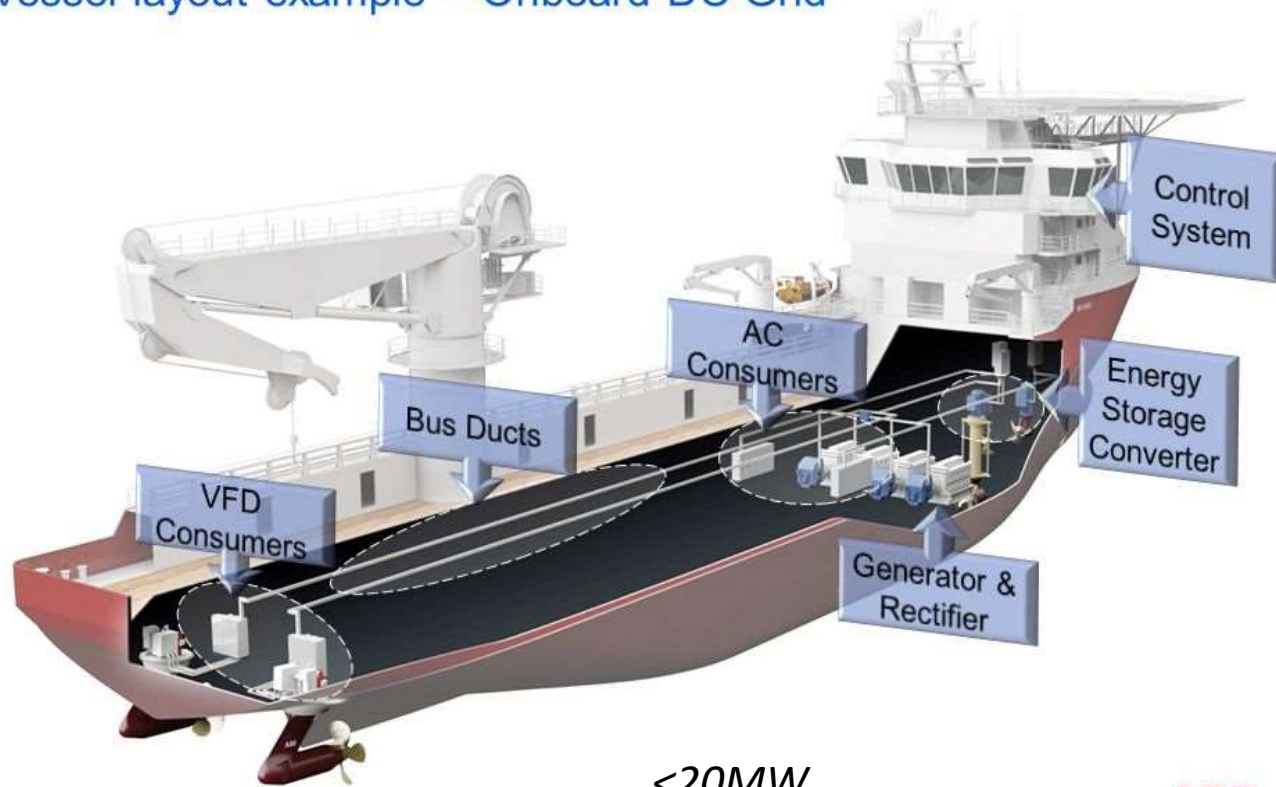


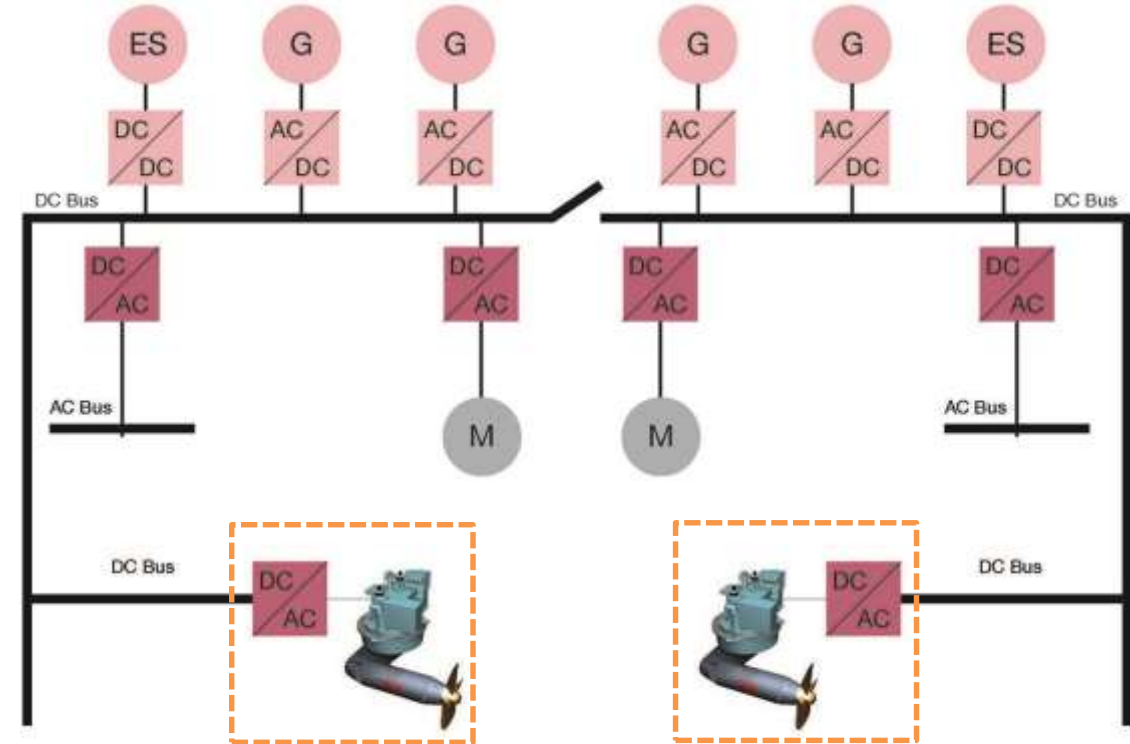
ABB Concept

Onboard DC Grid

Vessel layout example – Onboard DC Grid

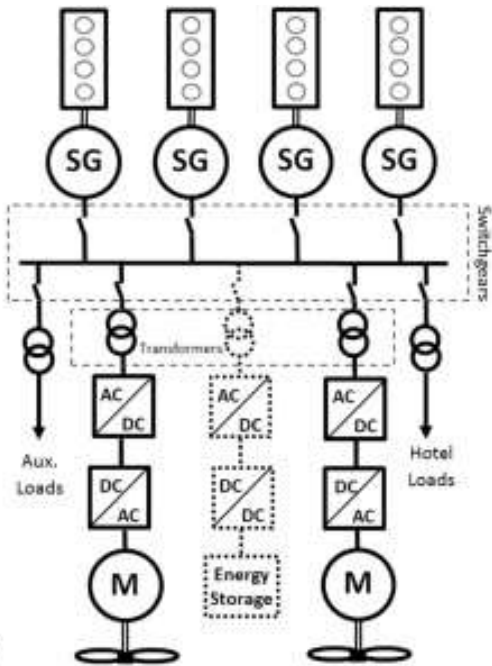


ABB

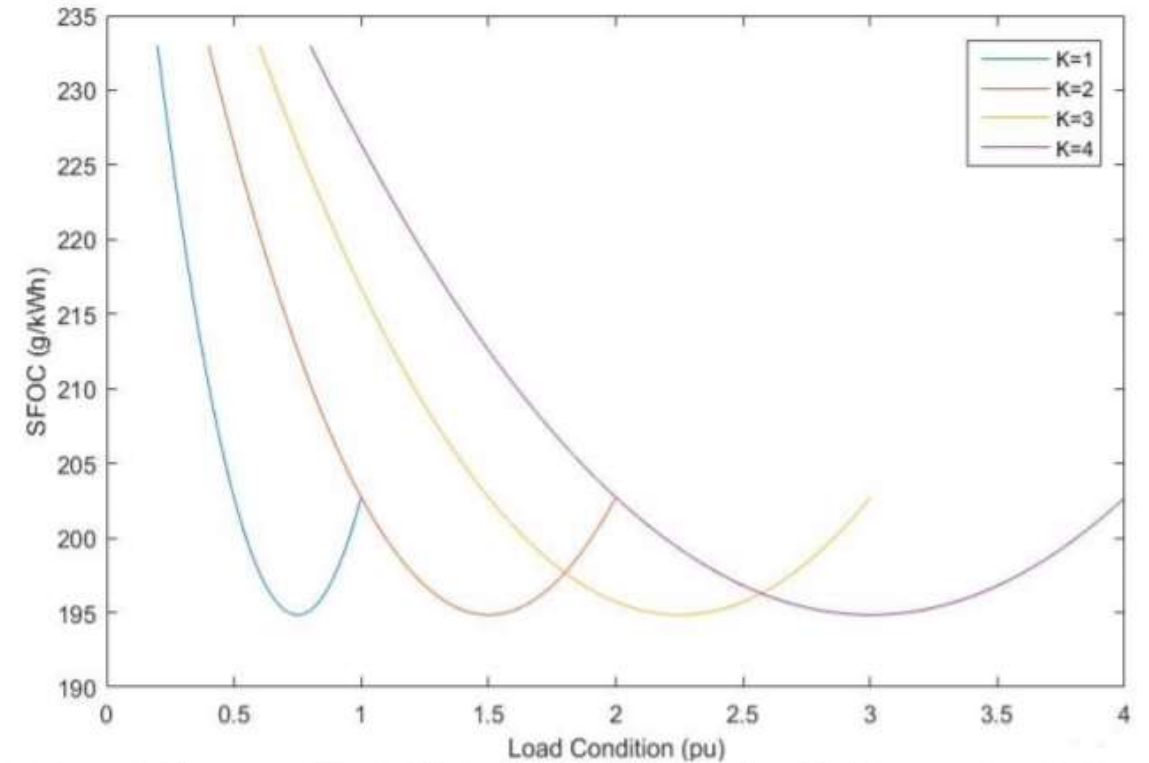
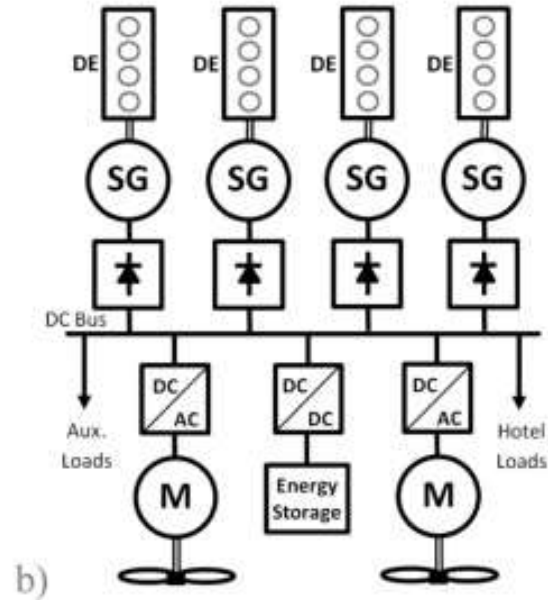


Source: ABB

AC SMG

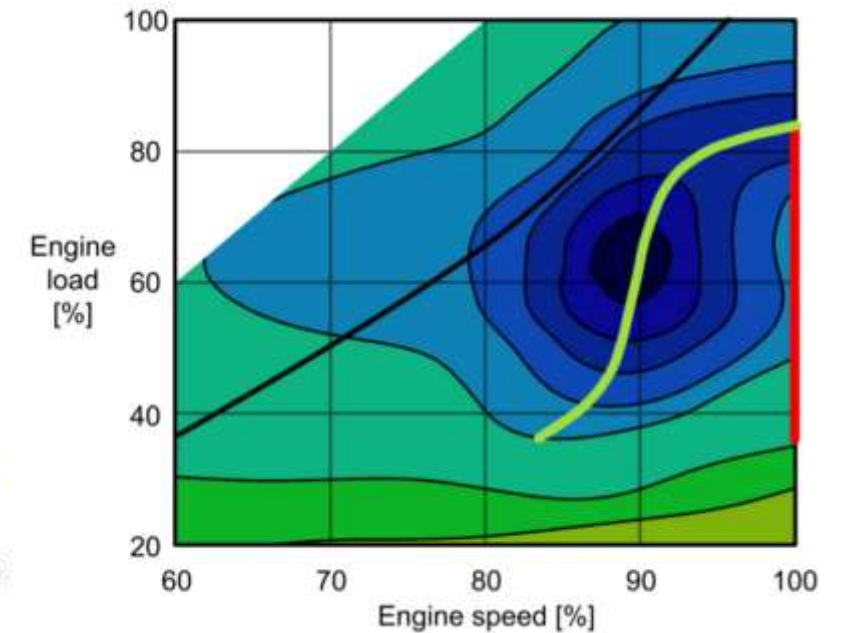
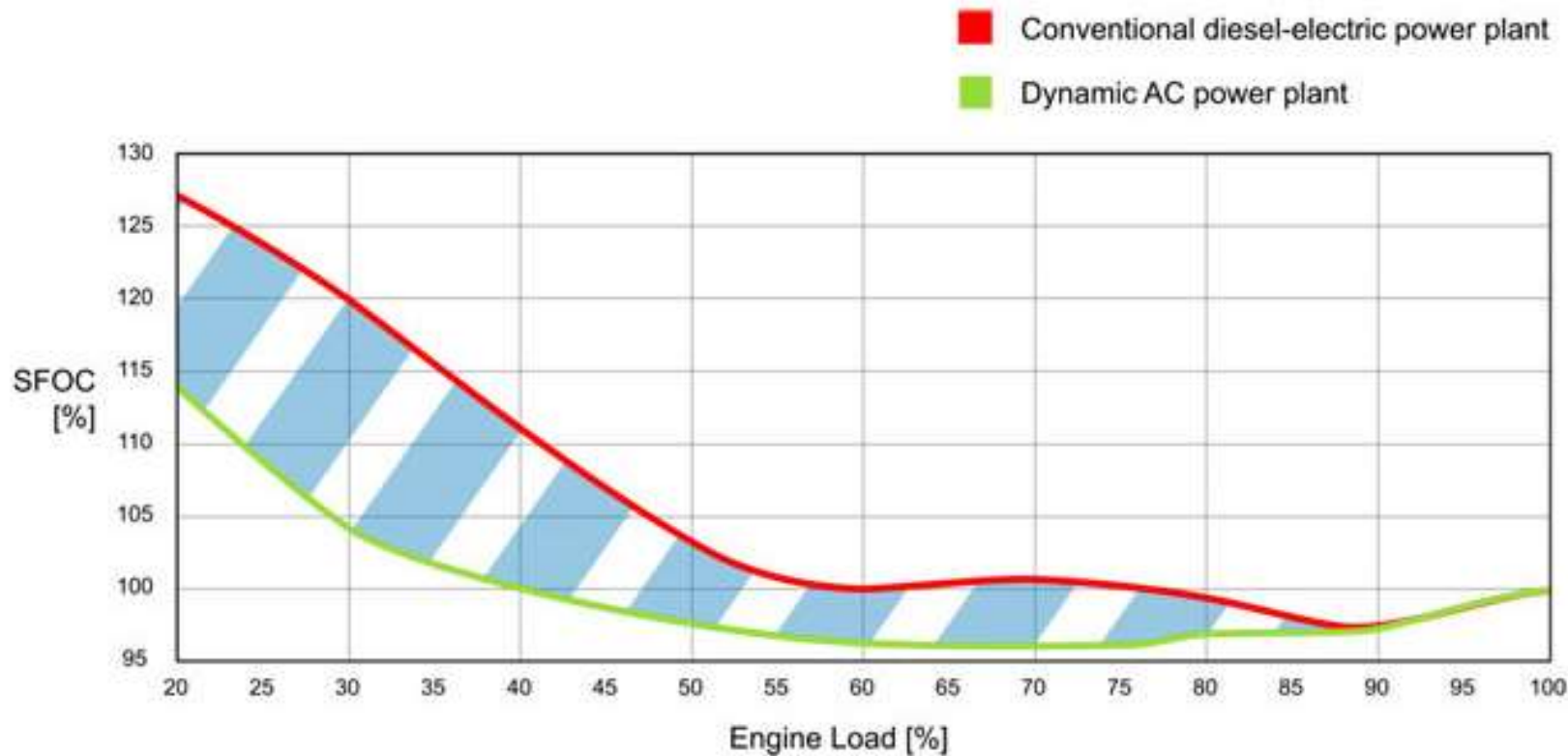


DC SMG



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

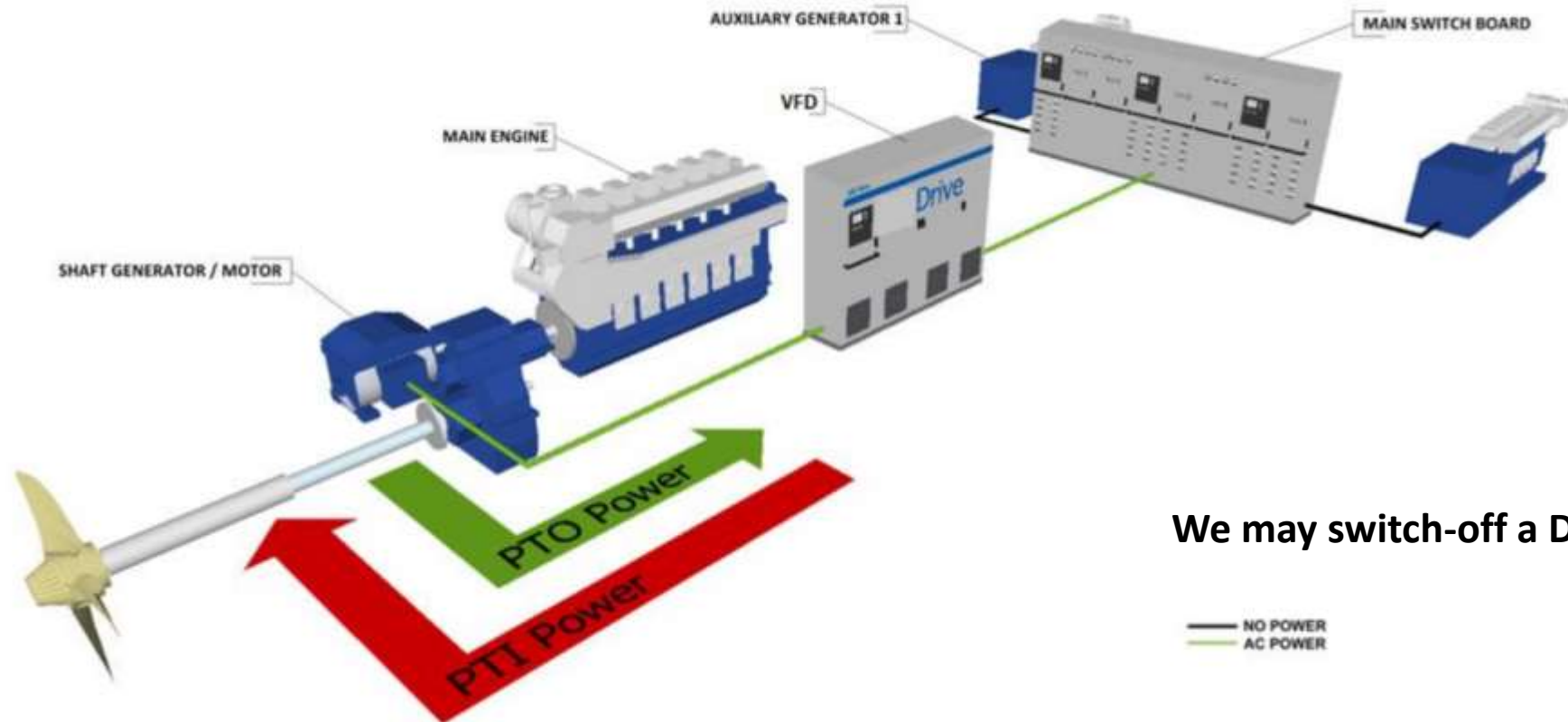
Dynamic AC concept – DAC by ABB



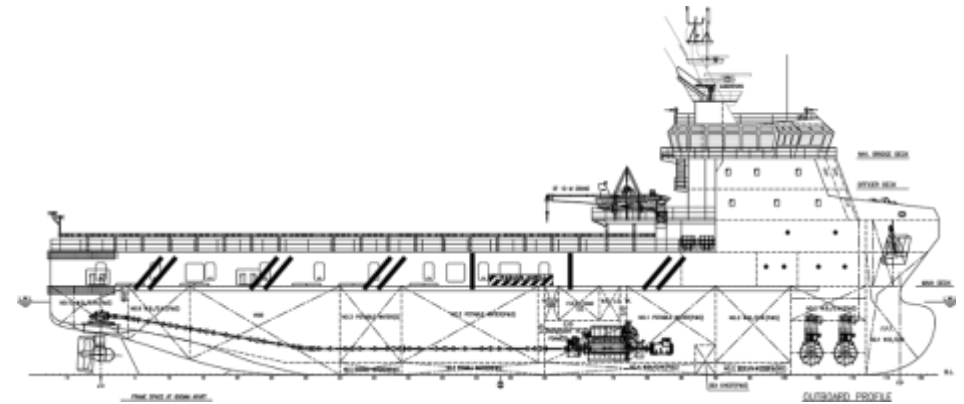
Benefits of Dynamic AC- Up to 6 % annual fuel savings for large cruise vessel (+20MW)

Source: ABB

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



Platform support vessel (PSV)

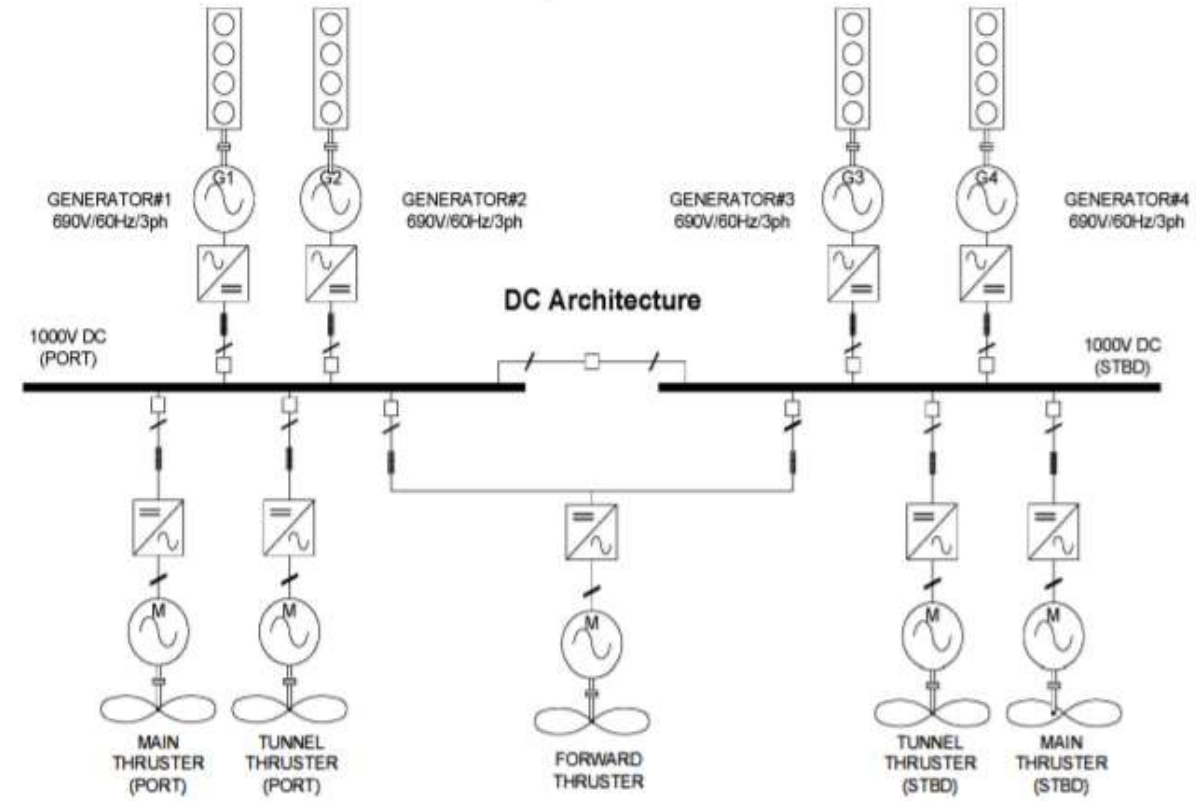
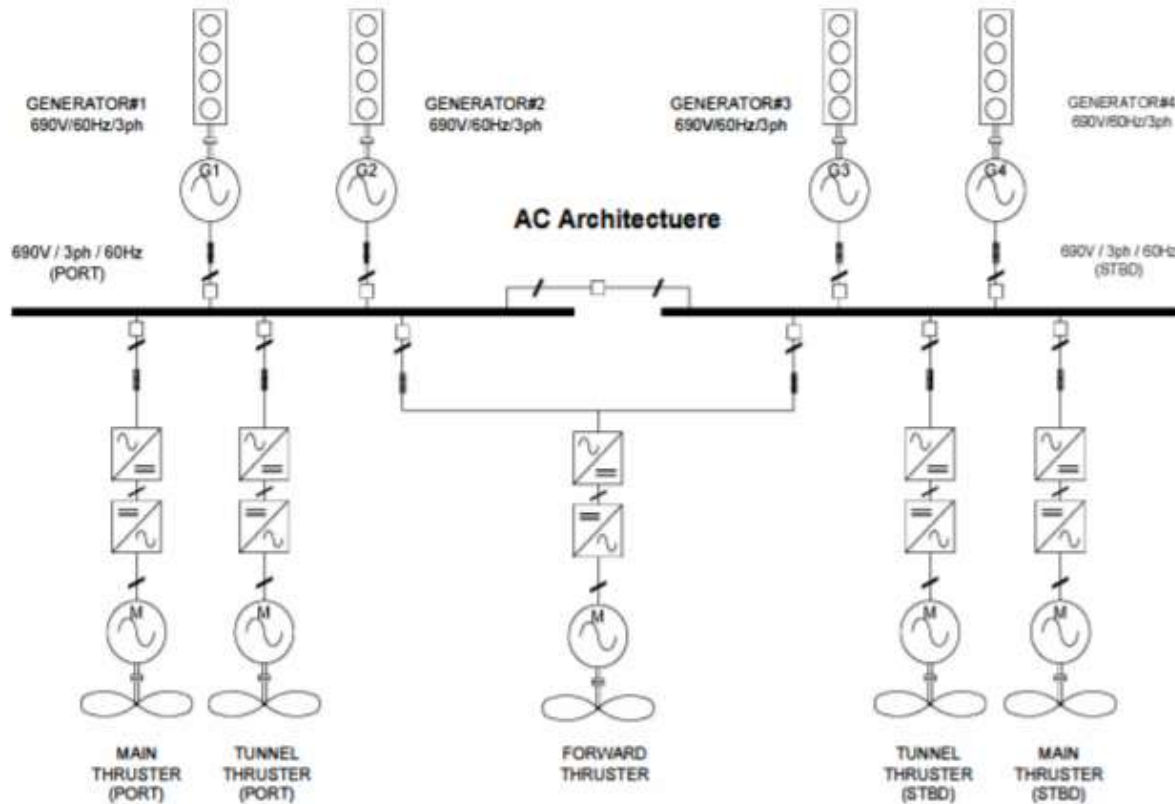


Platform support vessel (PSV)

AC

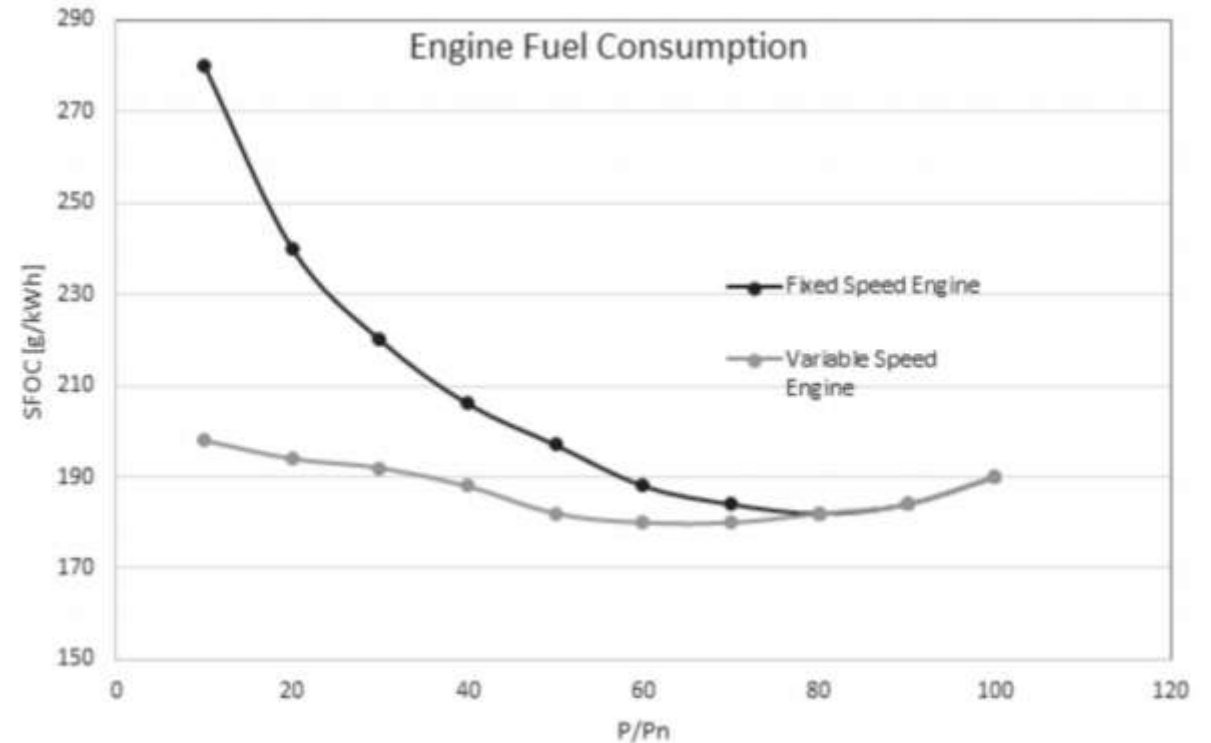


DC



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.

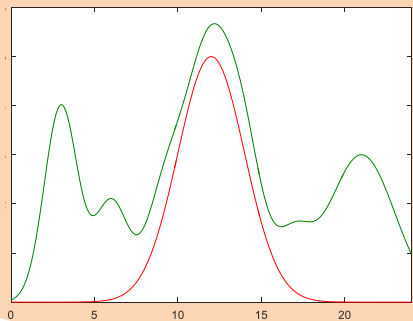


Rao, Srinivasa, et al. "An exercise to qualify LVAC and LVDC power system architectures for a Platform Supply Vessel." *Transportation Electrification Asia-Pacific (ITEC Asia-Pacific)*, 2016 IEEE Conference and Expo. IEEE, 2016.

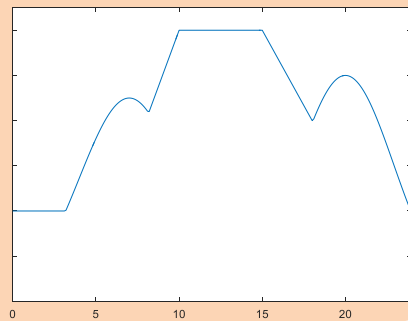
Terrestrial Microgrids V.S. Shipboard Microgrids:

Terrestrial Microgrids

Intermittent Renewables



Regular Loads



Intermittency Compensation



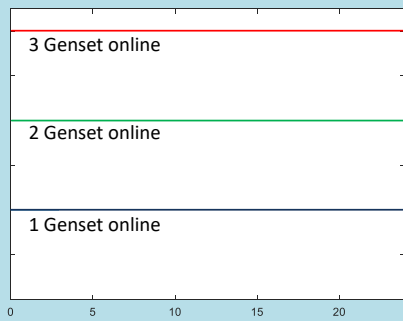
Mismatch in Generation & Consumption



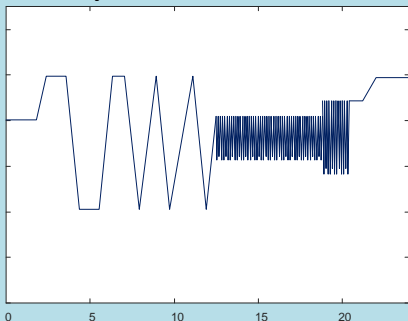
Instant Power Support

Shipboard Microgrids

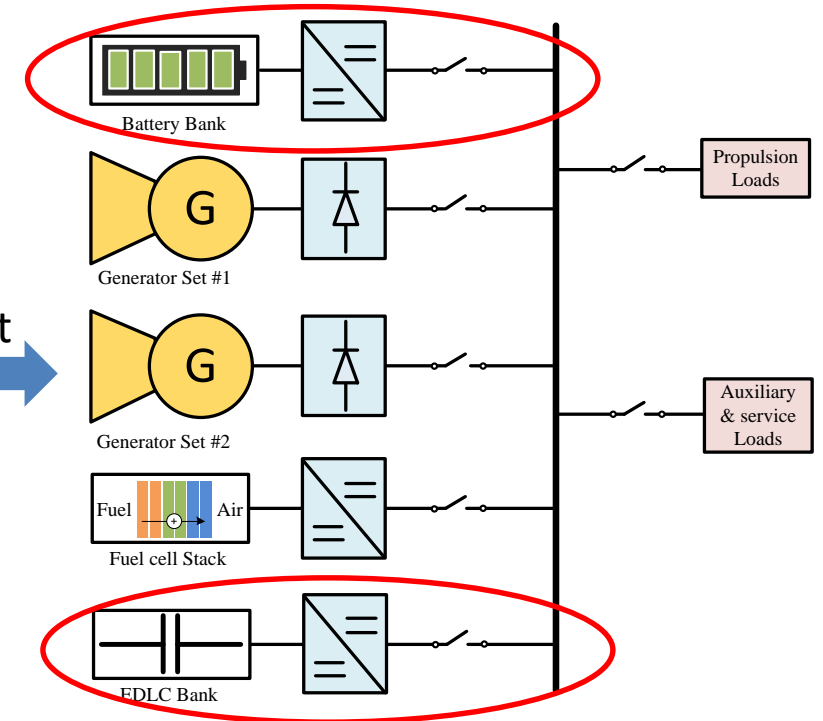
Economical Generation



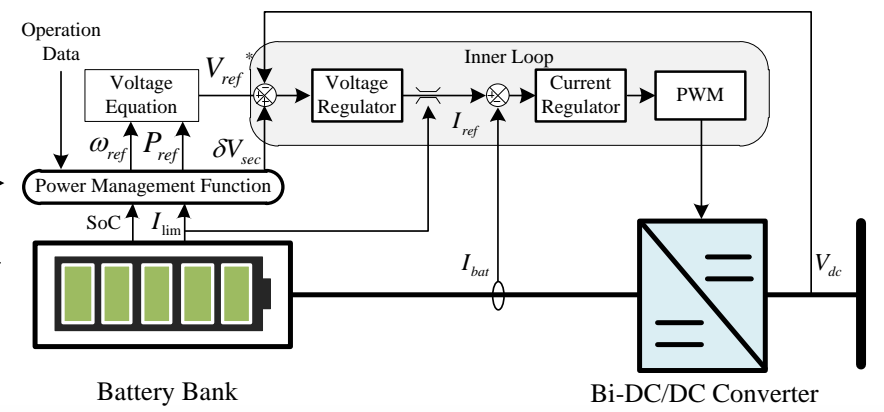
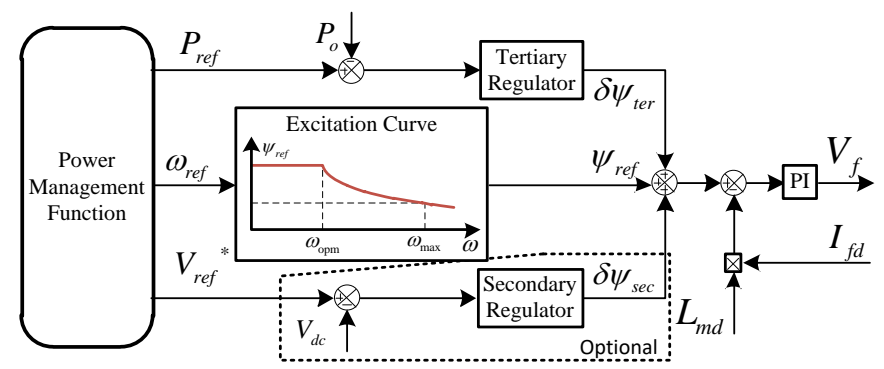
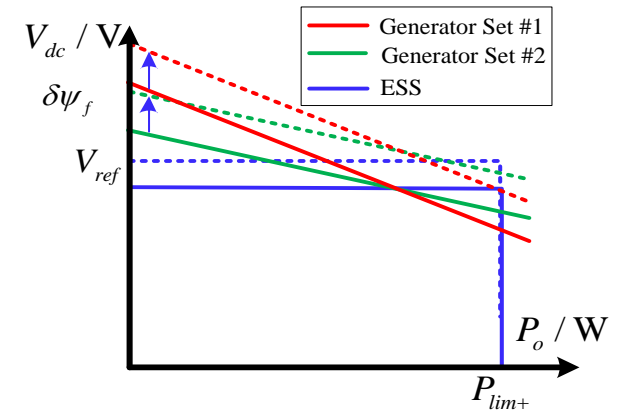
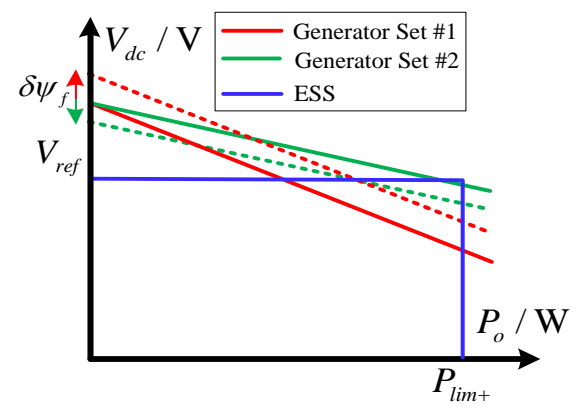
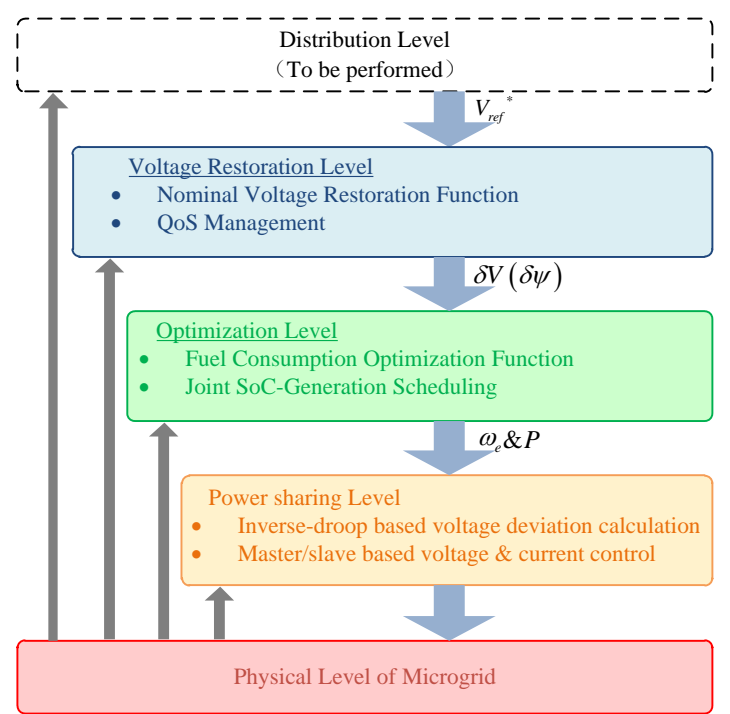
Dynamic Loads



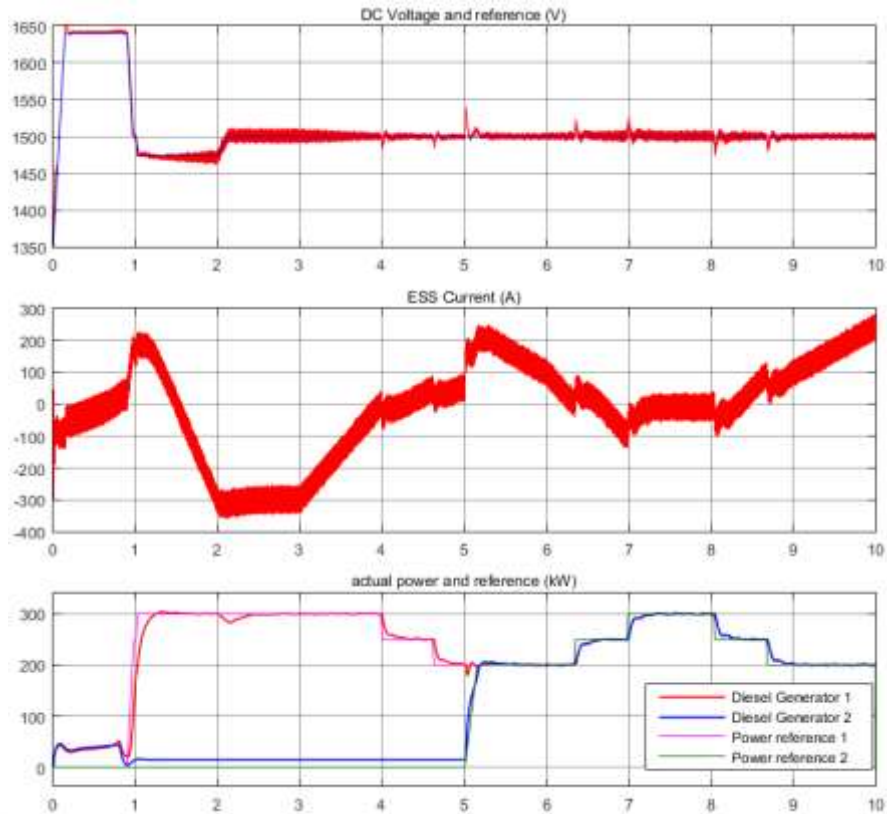
Control of Energy Storage Systems



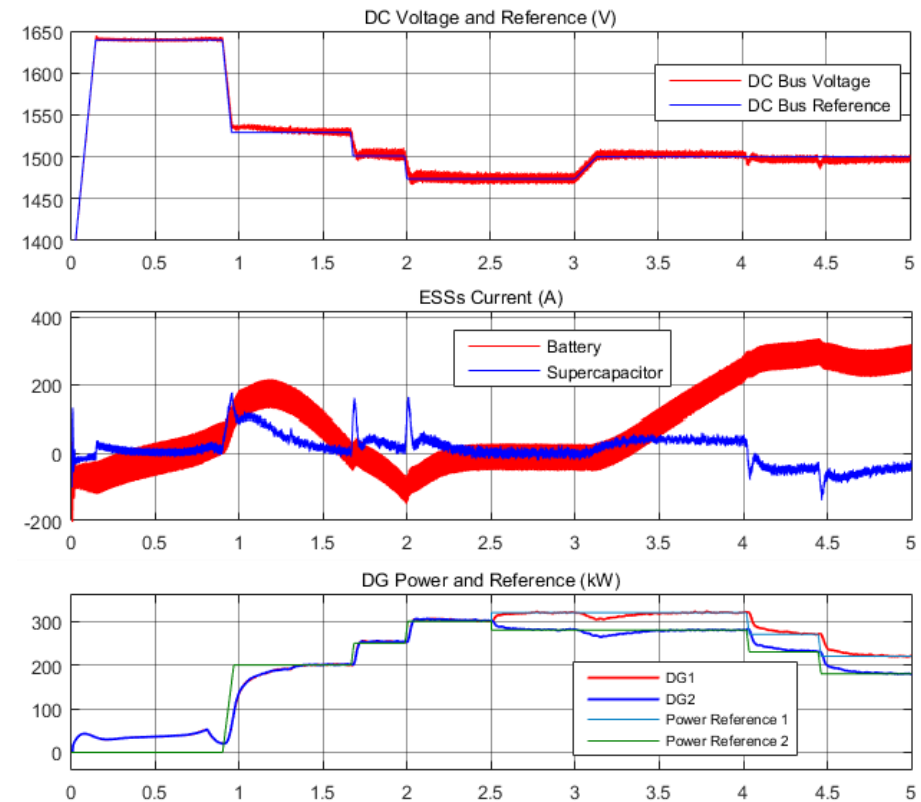
Higher levels design:



Real-time Simulation Results: Using Inverse-droop



Using Frequency-division Inverse-droop

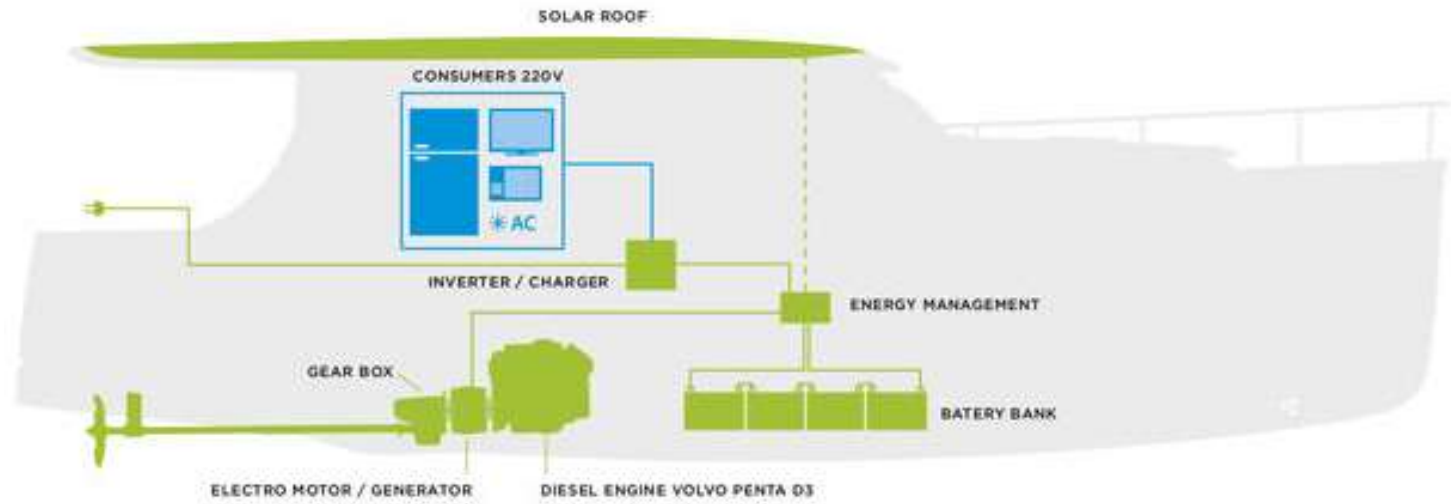




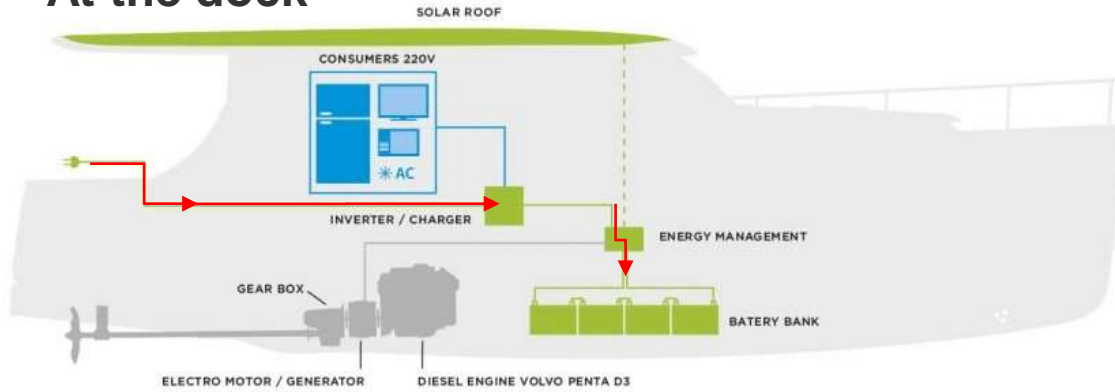
Lithium battery technology available: a 11,5 kWh on Greenline 33, 23 kWh on Greenline 40 and 46 kWh on Greenline 46 (battery pack with a permissible discharge of 100%).

www.greenlinehybrid.si

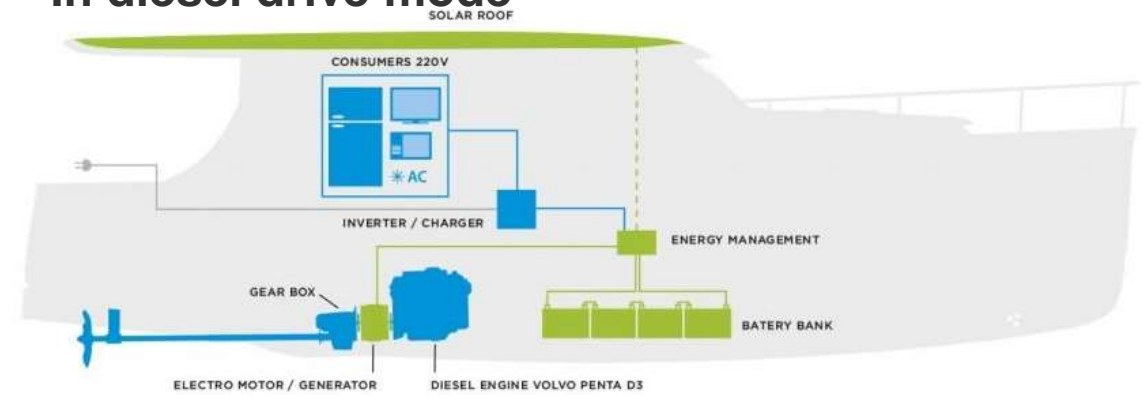
Hybrid Yachts



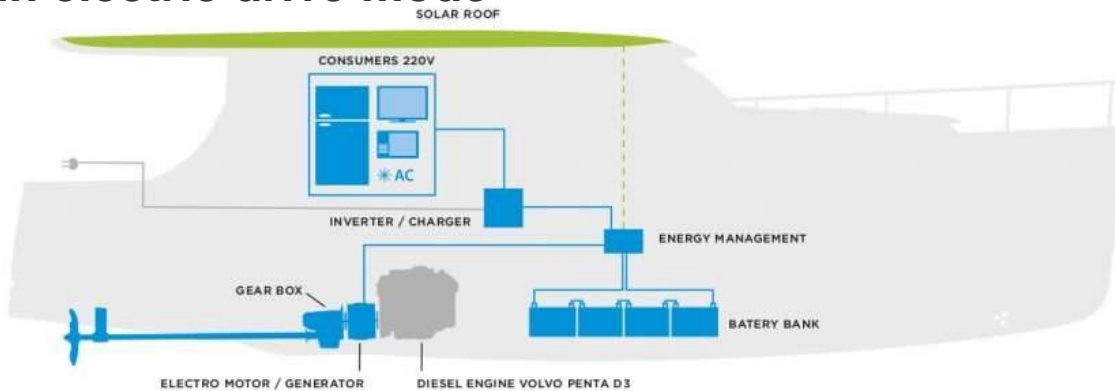
At the dock



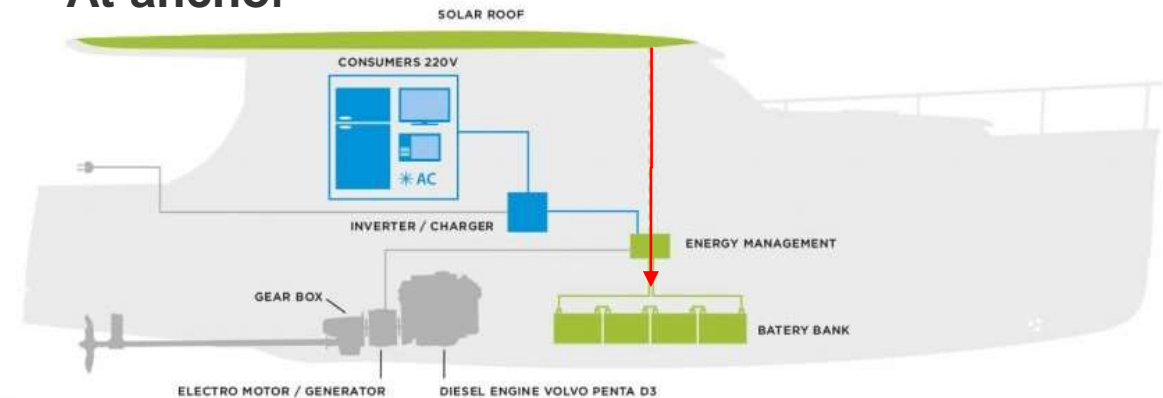
In diesel drive mode



In electric drive mode



At anchor





Scandlines

- 1 • Prinsesse Benedikte, built in 1997, hybrid since August 2013
- Capacity: 364 cars or 124/30 cars and lorries
- The world's largest hybrid ferry – 1.9 MWh battery bank
- The system equals approx. 400 hybrid cars
- Reduce CO2 emissions by 15 %



How you convert a ferry to hybrid



Worlds largest hybrid ferry fleet

Puttgarden - Rødby



Rostock - Gedser

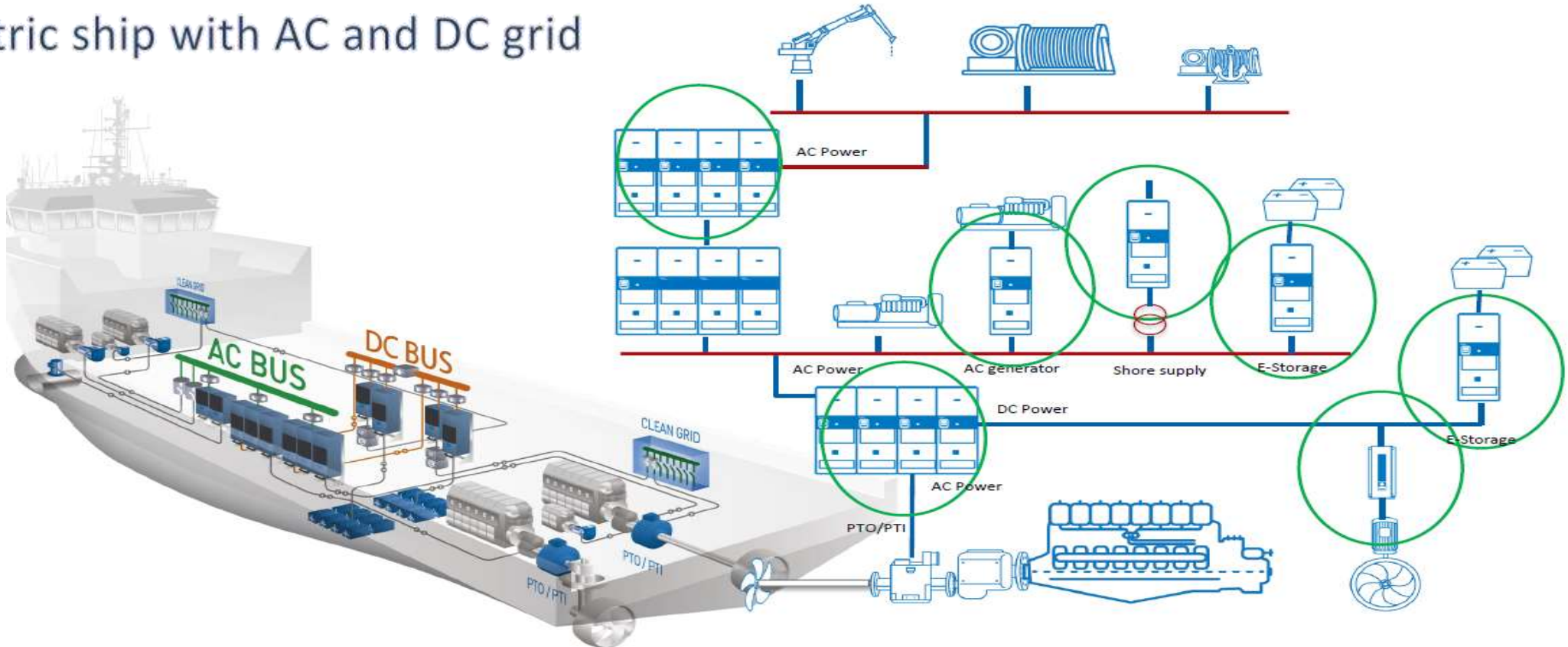


Source: Scandlines

- State-of-the-art and trends in SPS
- AC-DC grids in SPS
- ESS integration
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- Cold-Ironing

- State-of-the-art and trends in SPS
- AC-DC grids in SPS**
- ESS integration
- Power Quality Issues in SPS
- Cold-Ironing

Fully electric ship with AC and DC grid



Source: Vacon Power / Danfoss

Ampere Ferry from Norled (Norway)

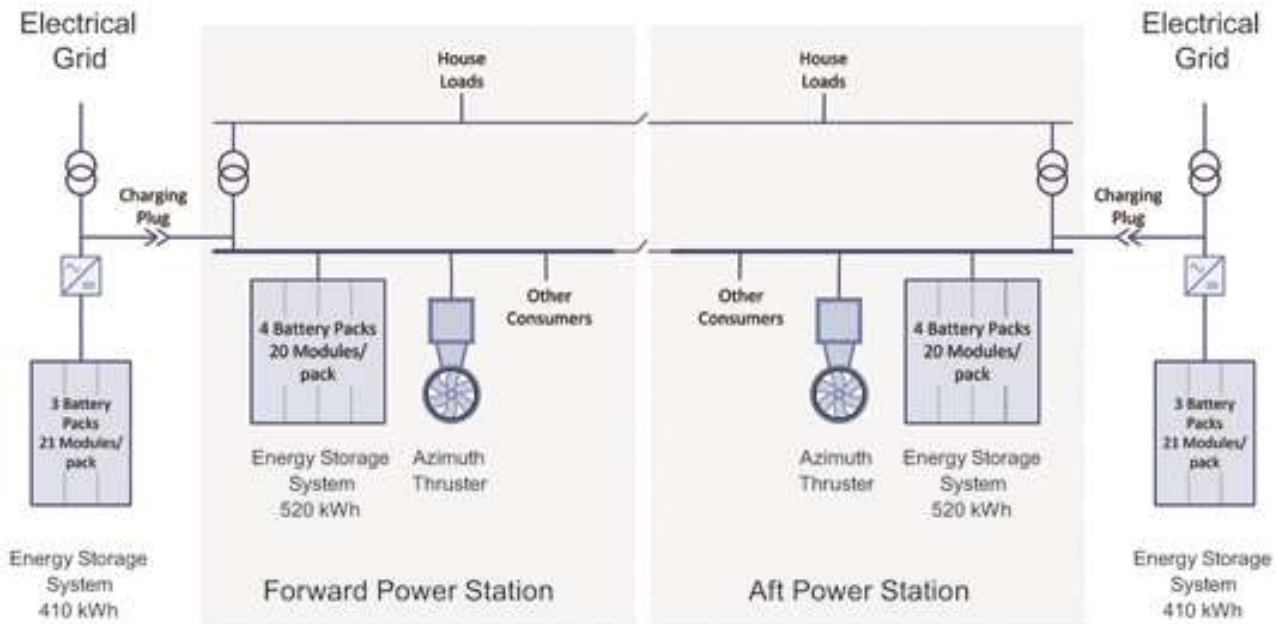


Norled AS, MF Ampere Ferry powered by Corvus Energy ESSs on both vessel and shore charging stations.



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

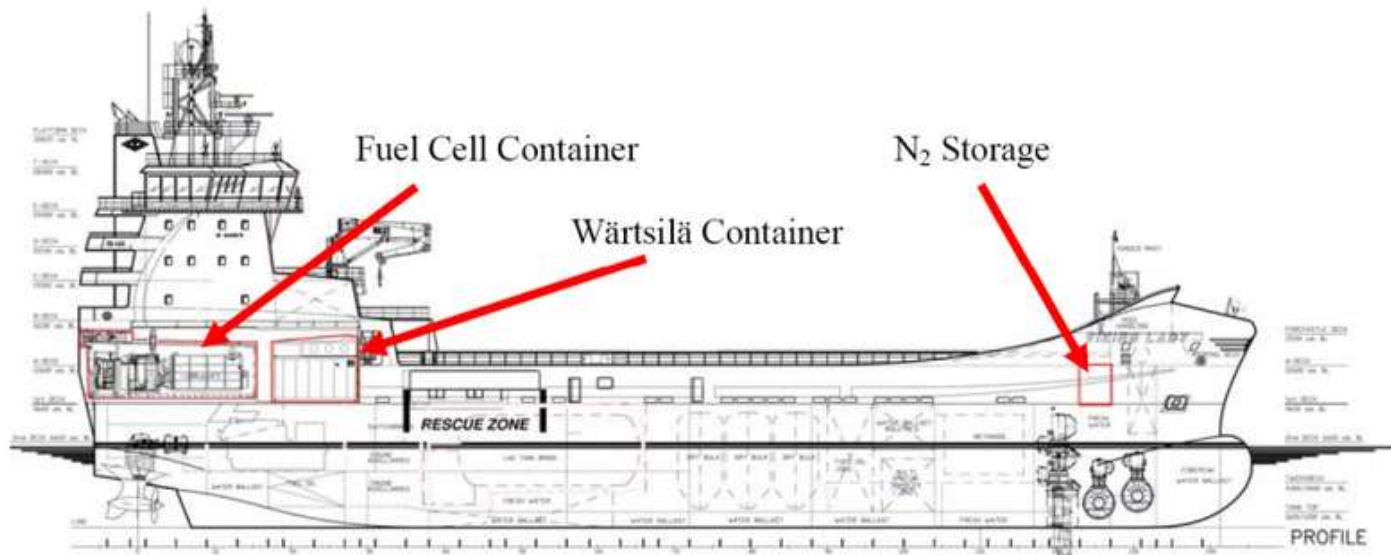
Offshore Supply Vessel: Viking Lady



- 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

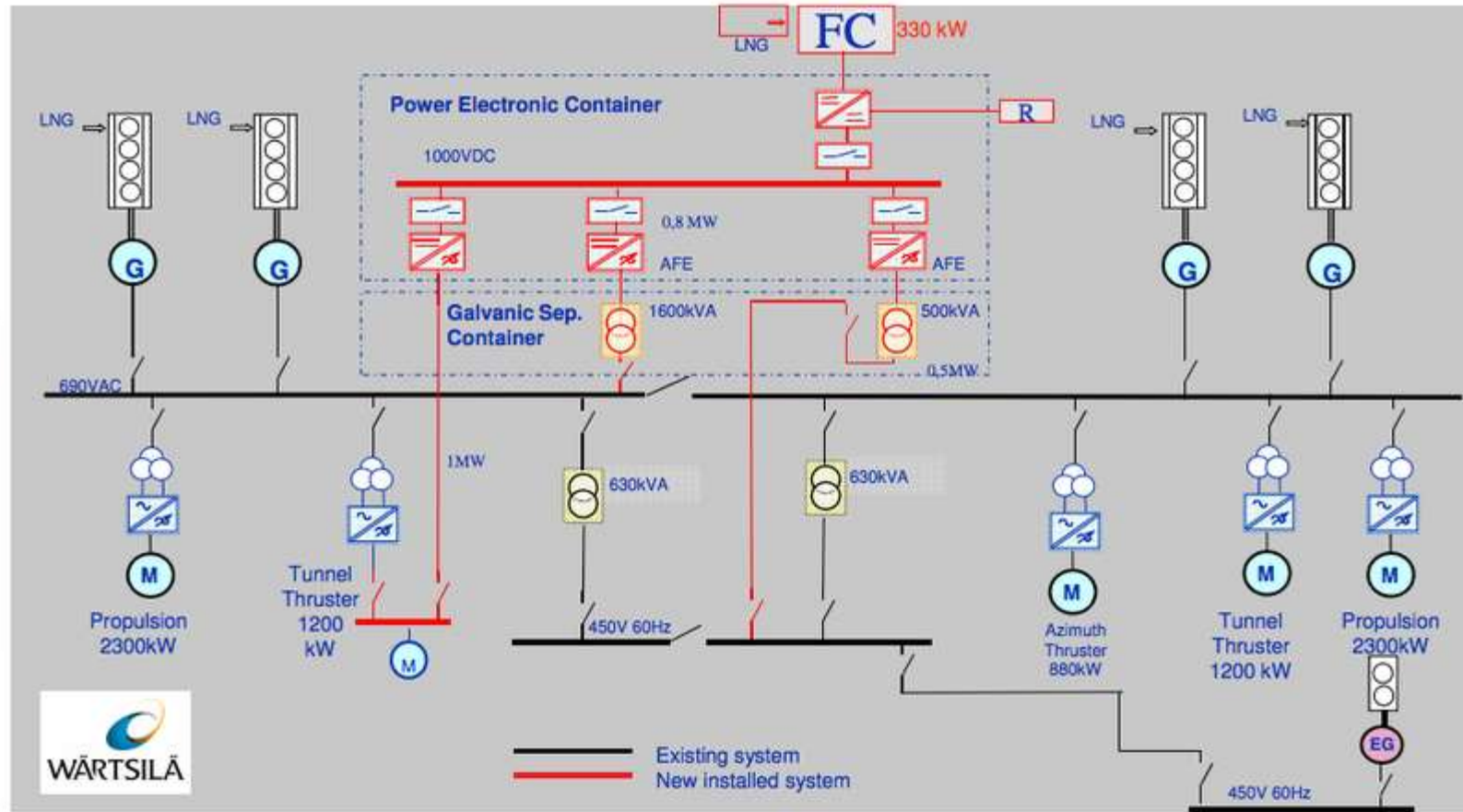
System integration



Source: Wärtsilä

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

Fuel cell integration in the electric propulsion system



Source: Wartsila



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



HyELEF project 2017

Hybrid Electrical Ferry including Batteries



AALBORG UNIVERSITY
DENMARK

VIS EDO
Electricity in Motion.



SOIC

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

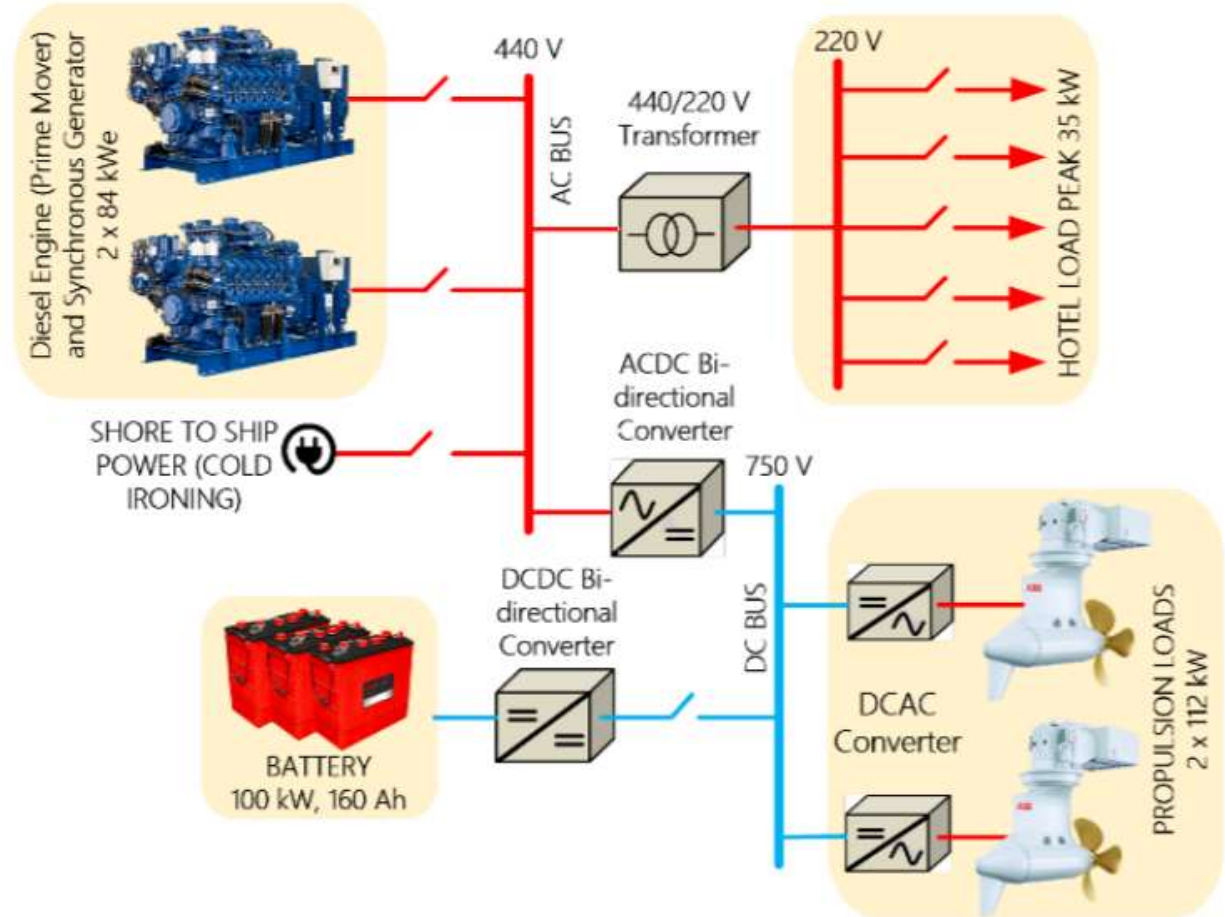
Ferry in Kaohsiung



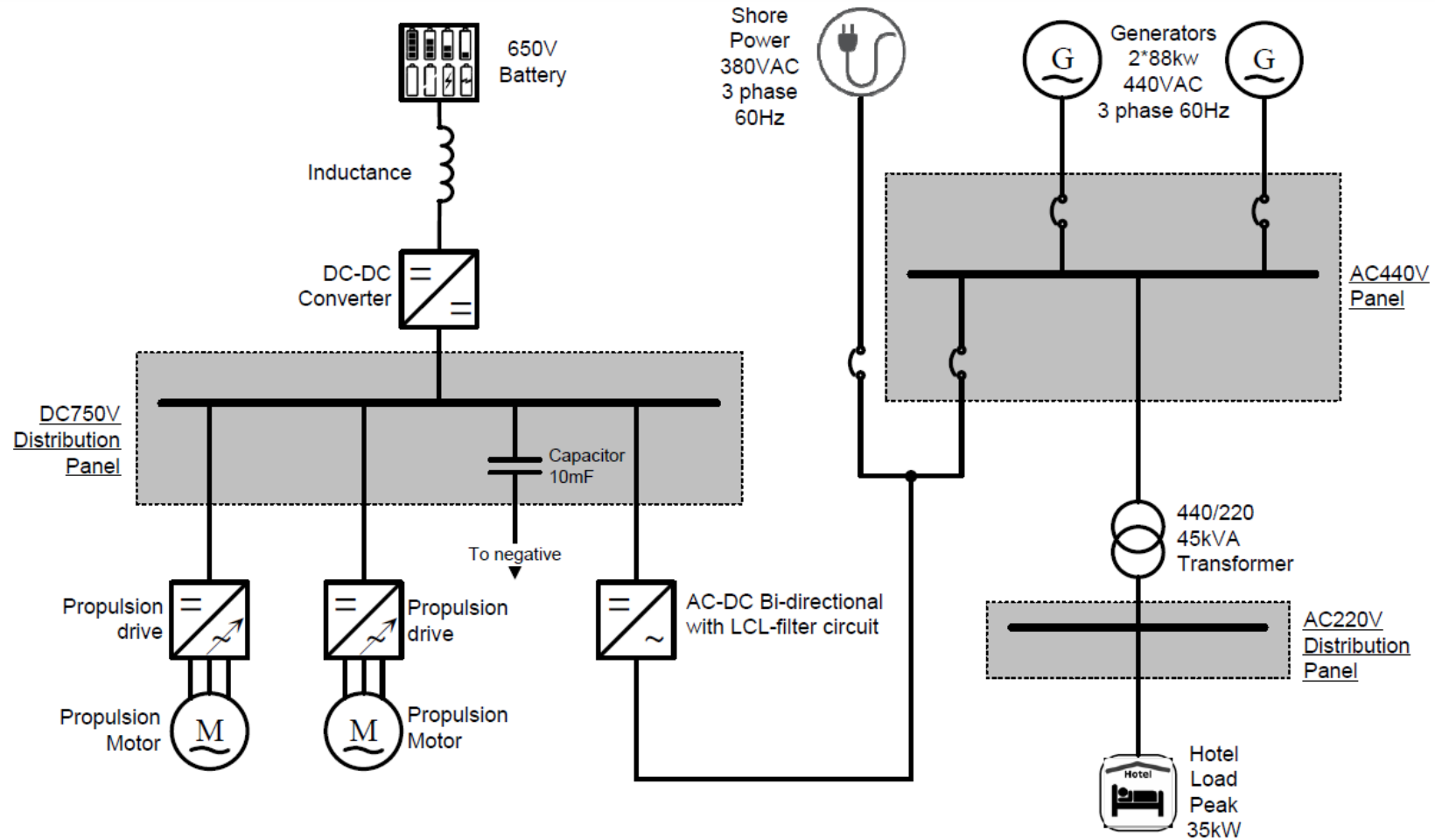
Ferry retrofitting



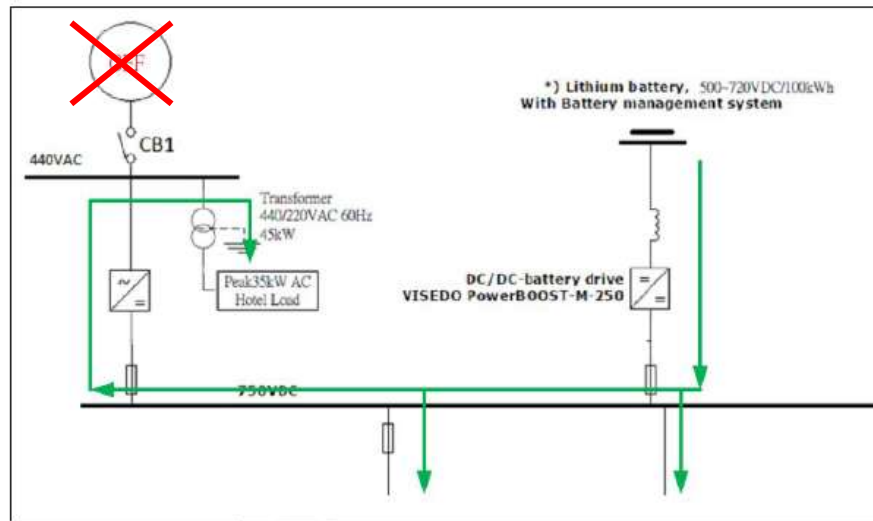
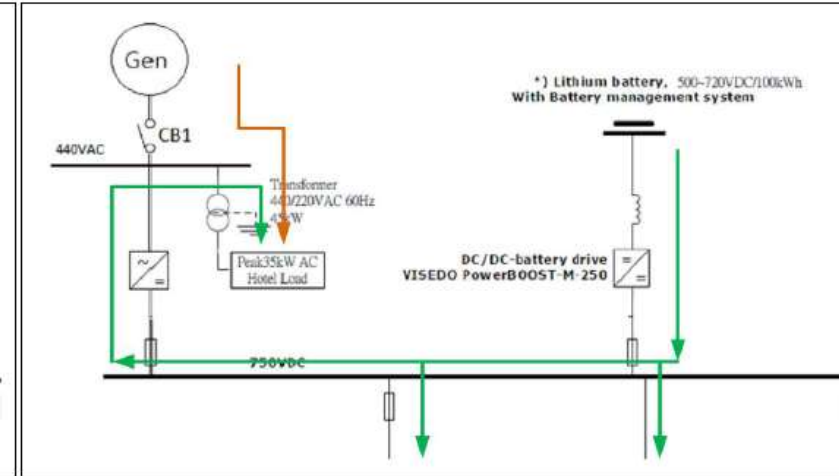
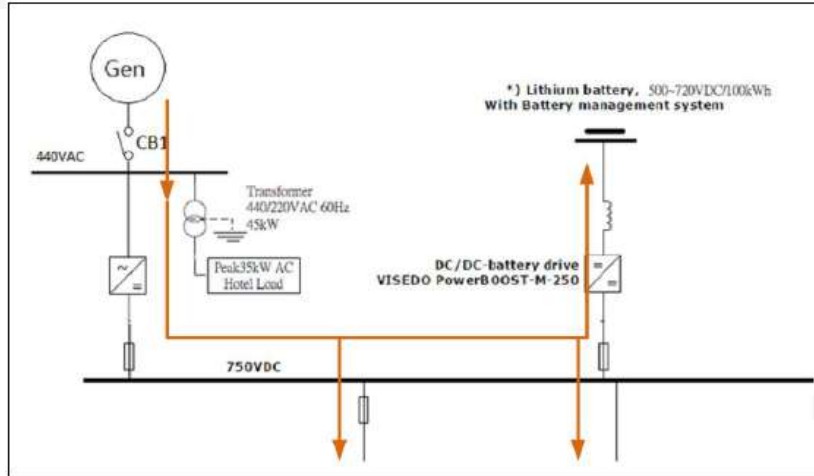
Asia's First Hybrid Electric Ferry



Asia's First Hybrid Electric Ferry



Asia's First Hybrid Electric Ferry



- AC Synchronization
- AC Dropping load share

Source: SOIC

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

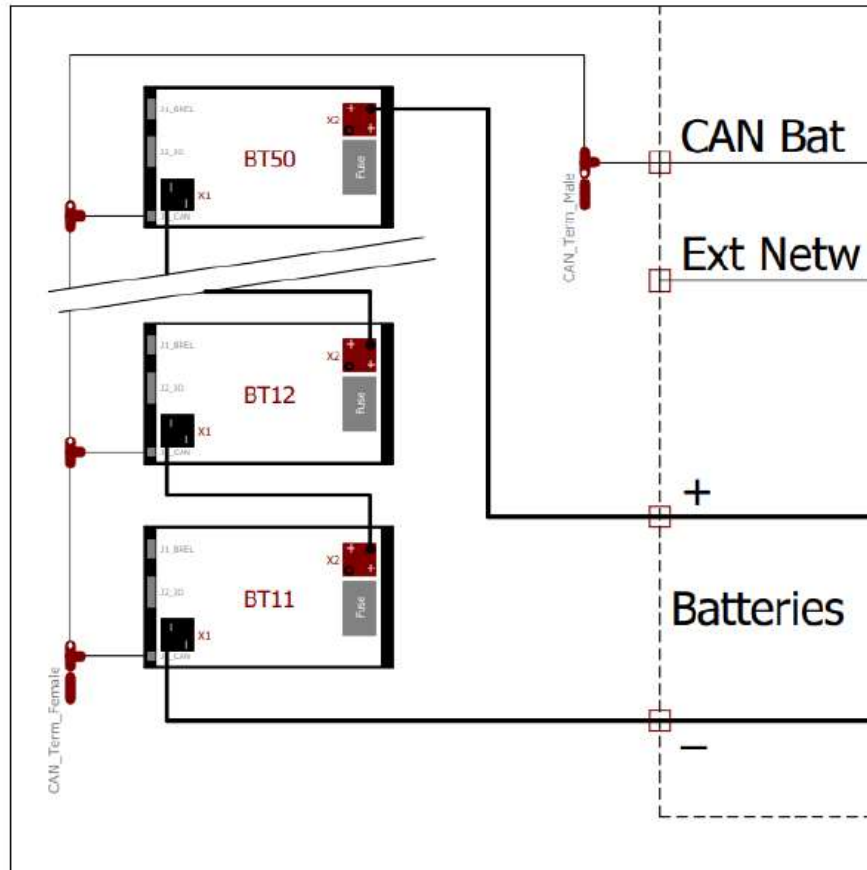


- Reconstruct storage room.
- Away from genset heat zone.
- Easy access for maintenance.



Source: SOIC

Asia's First Hybrid Electric Ferry



LITHIUM BATTERY | 13.2V/160 Ah
SB12V160E-ZC | (2.1kW LiFePO4)

➤ 50 modules in series, 105kWh, 500~720VDC.

Source: SOIC

Asia's First Hybrid Electric Ferry



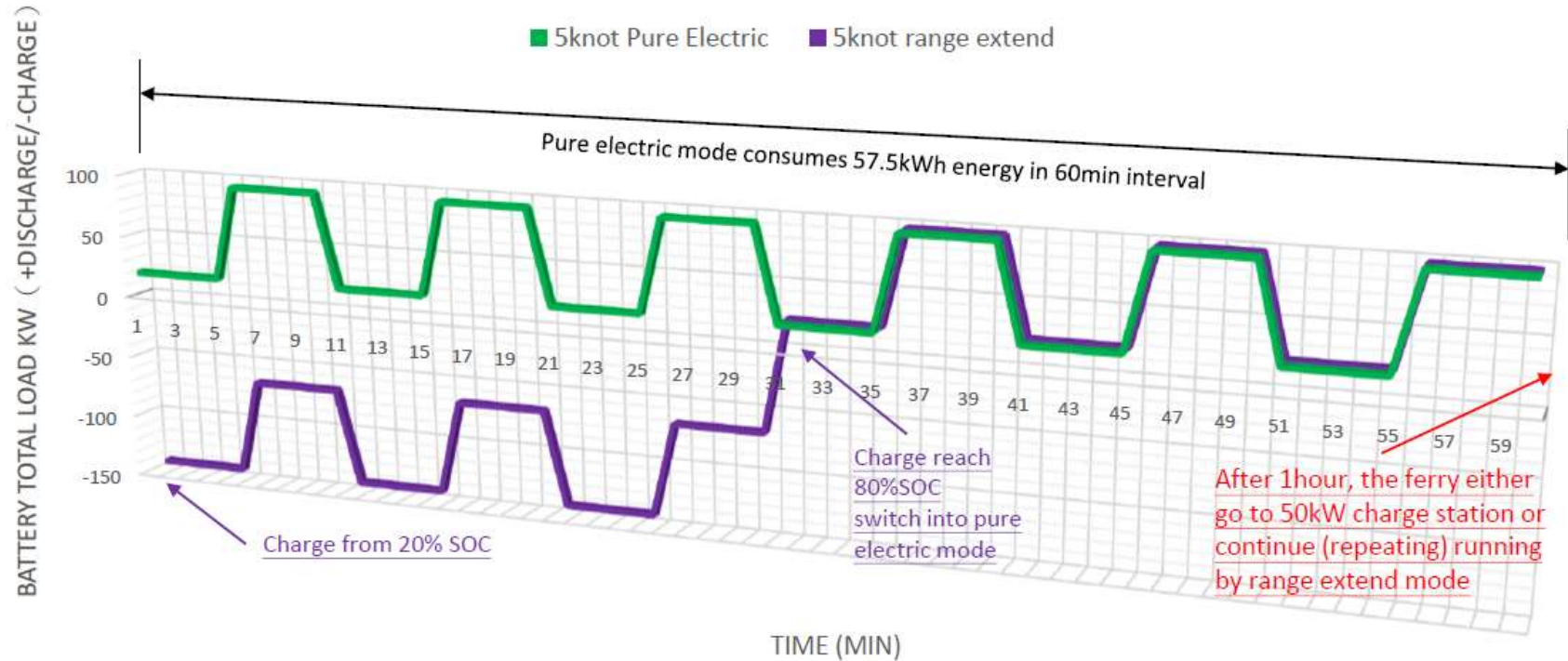
- DC/DC, DC/AC, LCL, Inductor.
- Extreme compact size.
- Very low heat generate.



Source: SOIC

Asia's First Hybrid Electric Ferry

e-ferry battery load profile
(100kWh@20%~80%SOC \doteq 57.5kWh Useage)

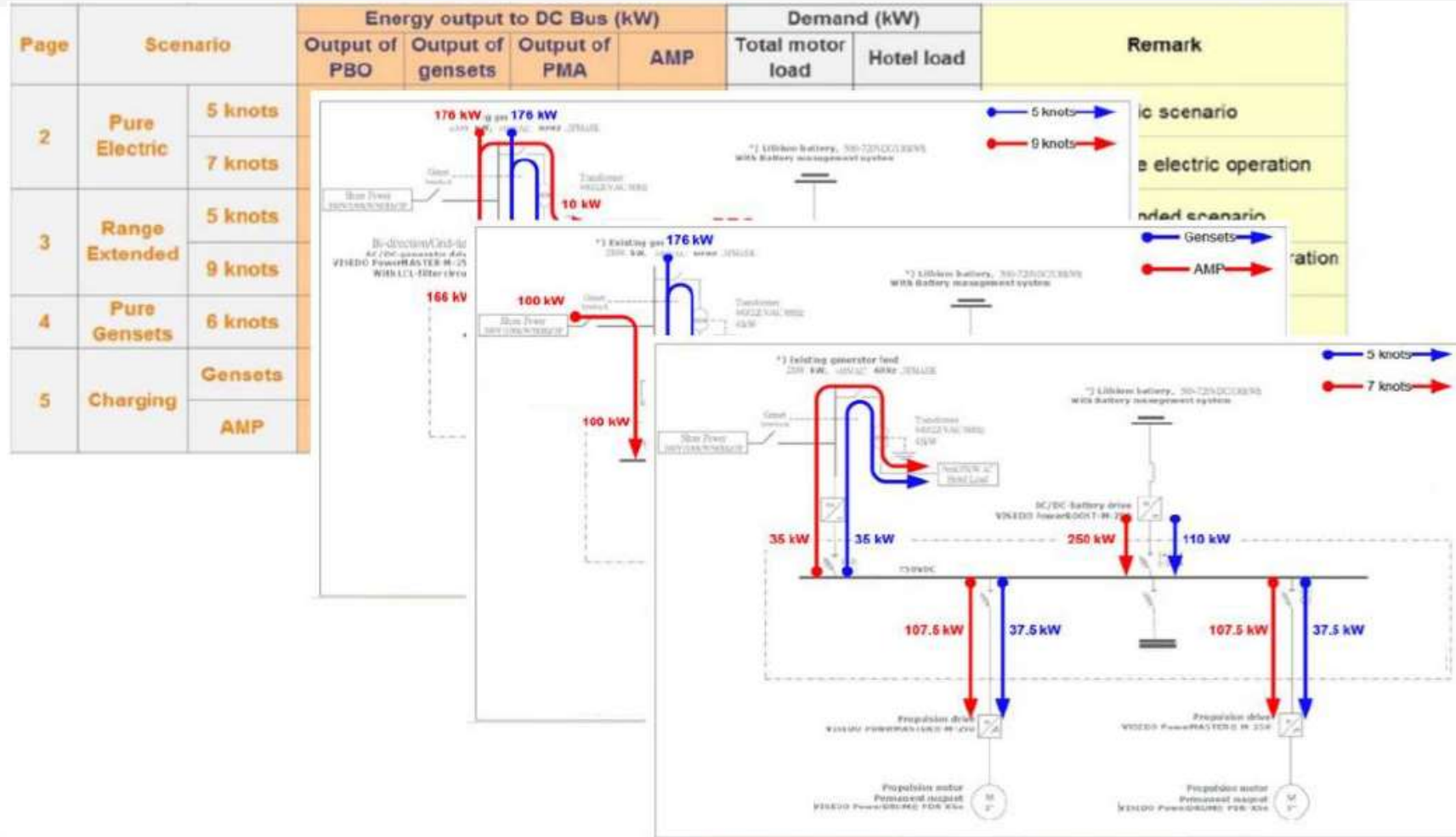


- Every one hour running, the boat can either continue by range extend or stop and doing shore 50kW one hour charging.

Source: SOIC

Asia's First Hybrid Electric Ferry

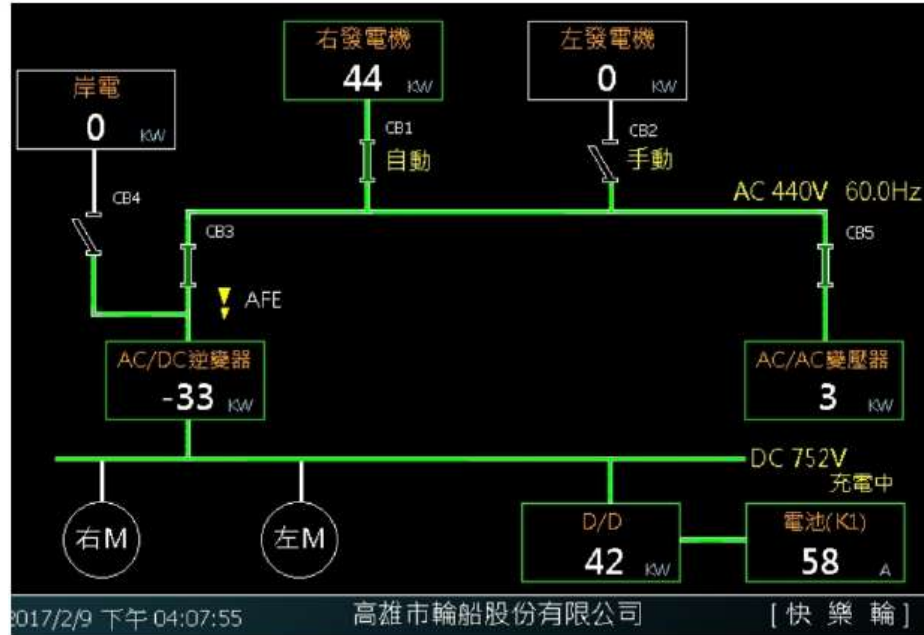
Power flow analysis



Source: SOIC

Asia's First Hybrid Electric Ferry

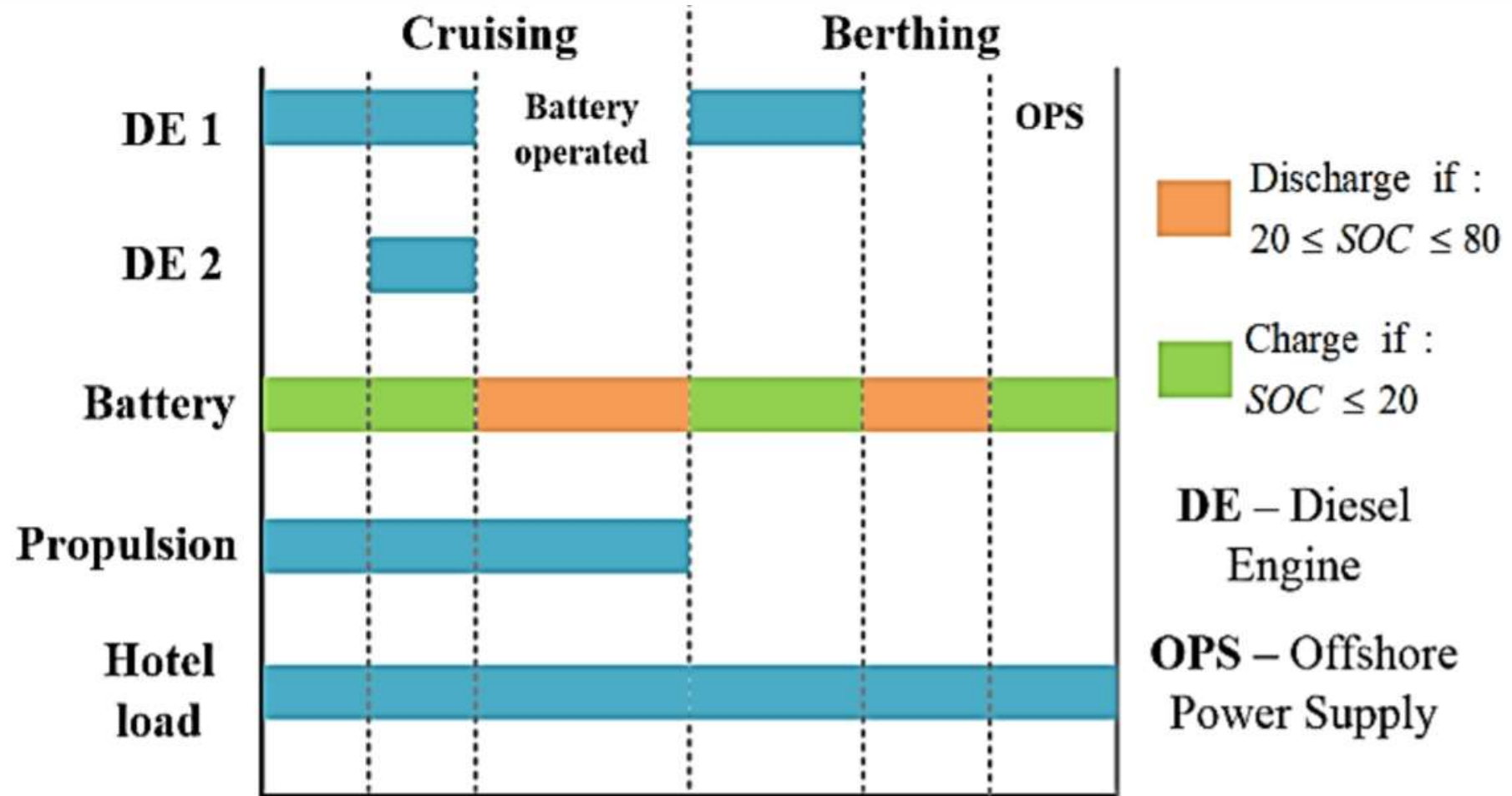
PMS



- 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

- State-of-the-art and trends in SPS
- AC-DC grids in SPS
- ESS integration
- Power Quality Issues in SPS
- Cold-Ironing

- State-of-the-art and trends in SPS
- AC-DC grids in SPS
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EFFICIENSEA project 2014-2018

Off-shore Application of the Flywheel Energy Storage System



AALBORG UNIVERSITY
DENMARK



**MAERSK
DRILLING**



WattsUp Power

- 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

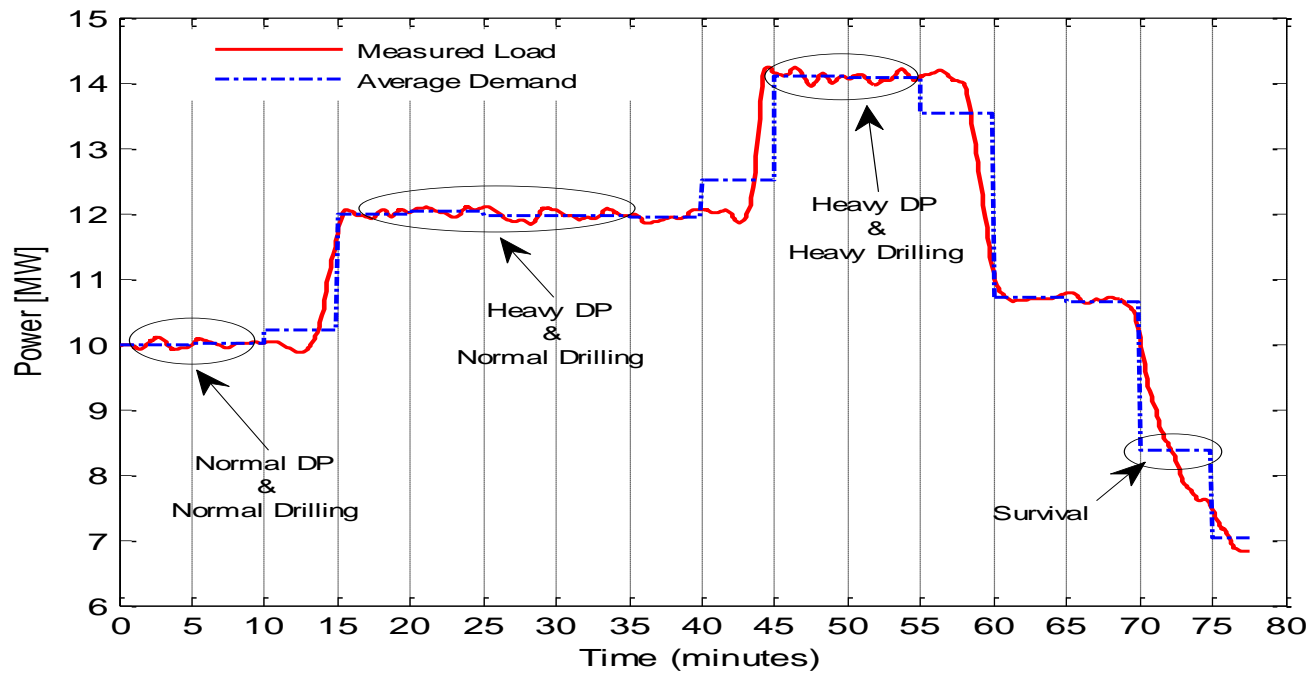
Duration: 3 years



© MAERSK DRILLING



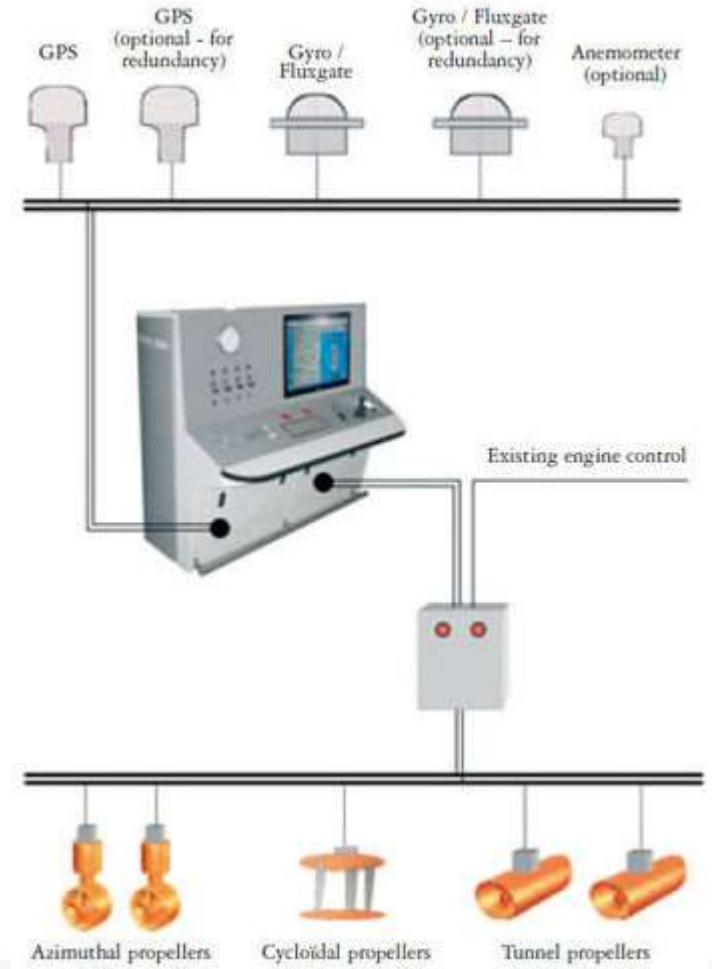
© MAERSK DRILLING



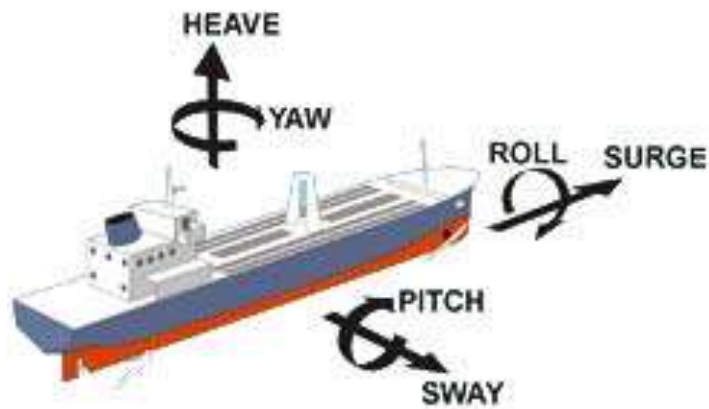
Source: www.flywheel.et.aau.dk

Dynamic Positioning (DP)

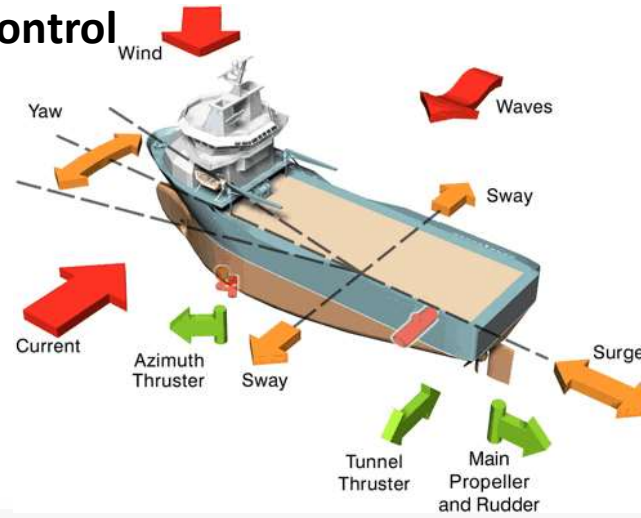
Dynamic Positioning (DP) is a computer-controlled system that automatically maintains a vessel's position and heading.



Forces and motions



DP Control



Dynamic Positioning (DP)



Dynamic Positioning (DP)

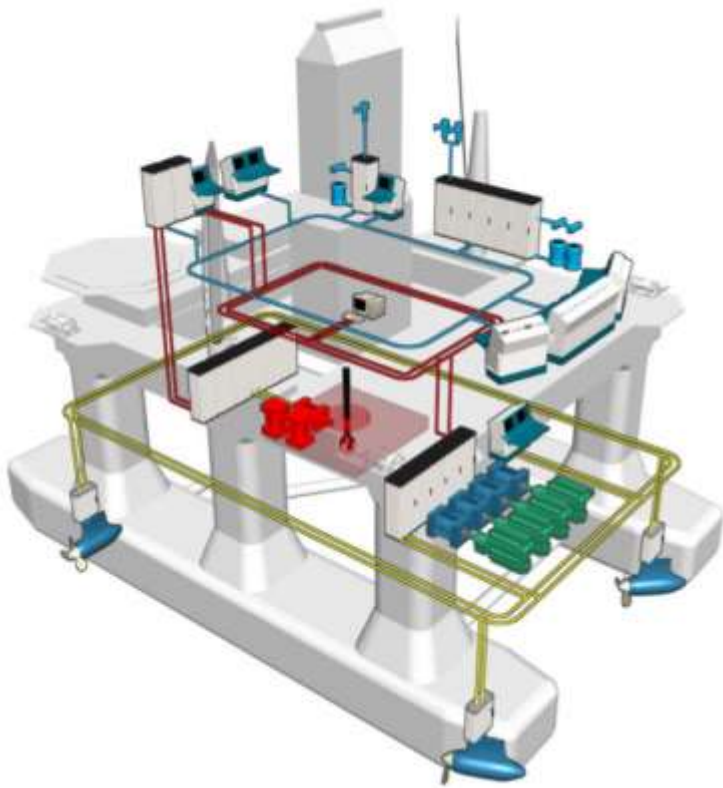
Example of configuration for Dynamic Positioning system



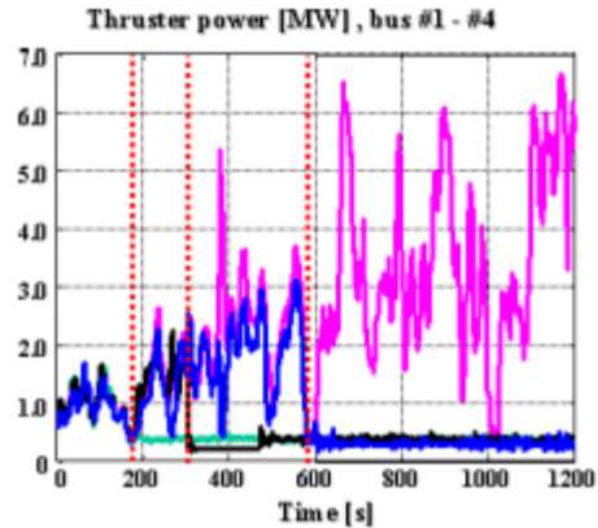
WEST VENTURE
Type:
Semi-submersible
Location:
Norway
Availability:
Available
Maximum depth:
2,600 feet

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

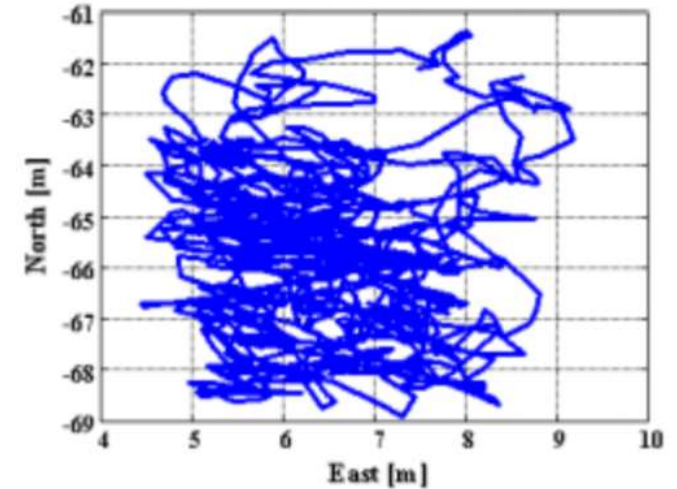
Semi submersible drilling rig with
four podded azimuthing thrusters



Full-scale data from West Venture

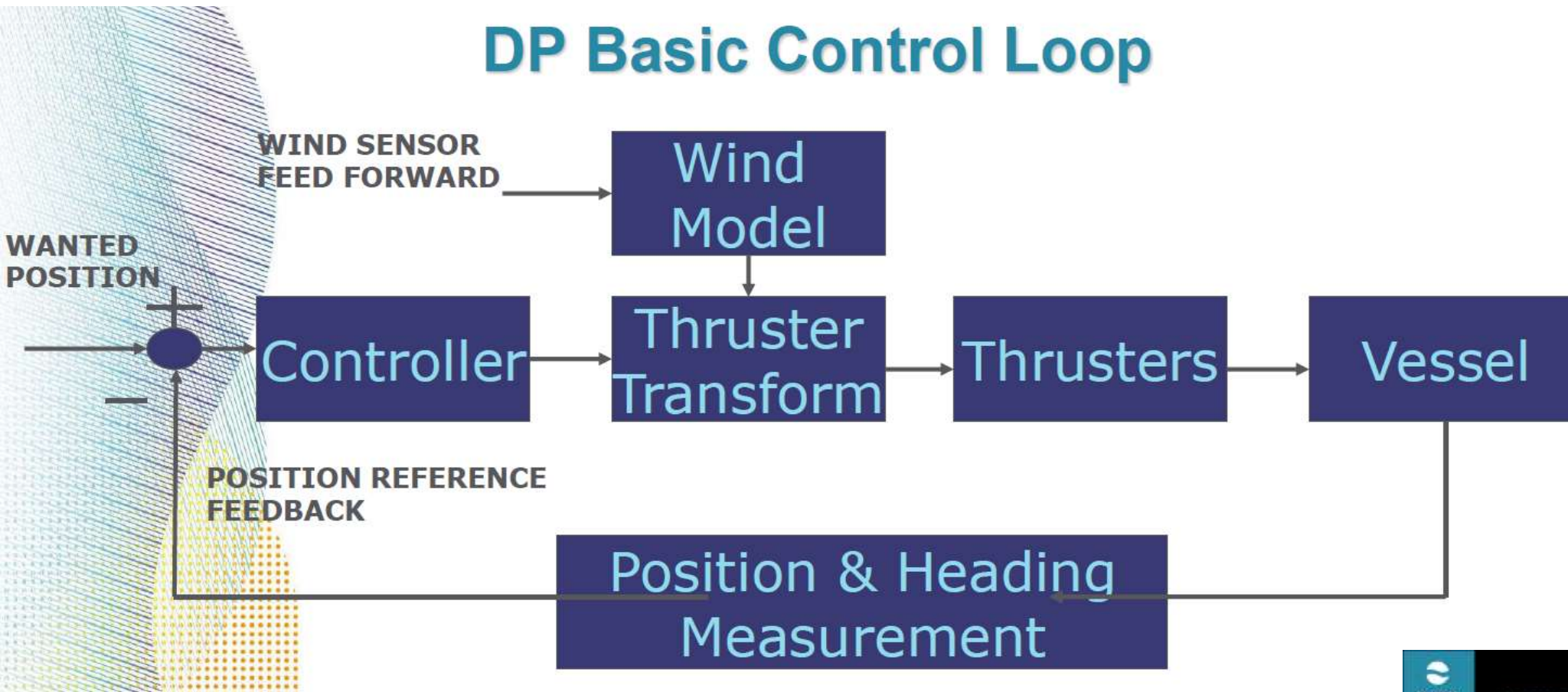


Vessel position.

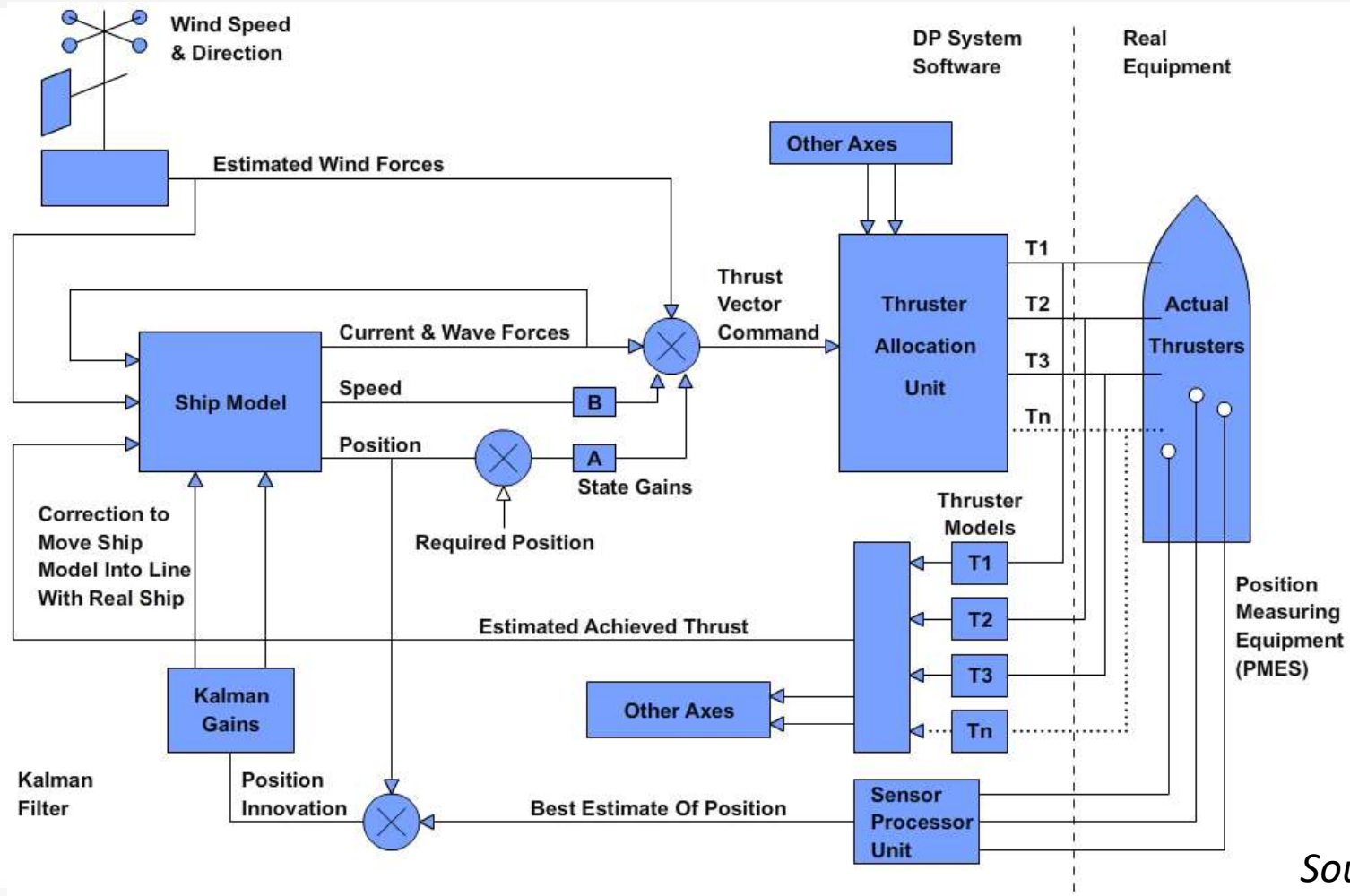


Dotted lines: when available power on the busses are reduced to 0,3 MW
Solid line: the total thruster power on each bus

DP Basic Control Loop

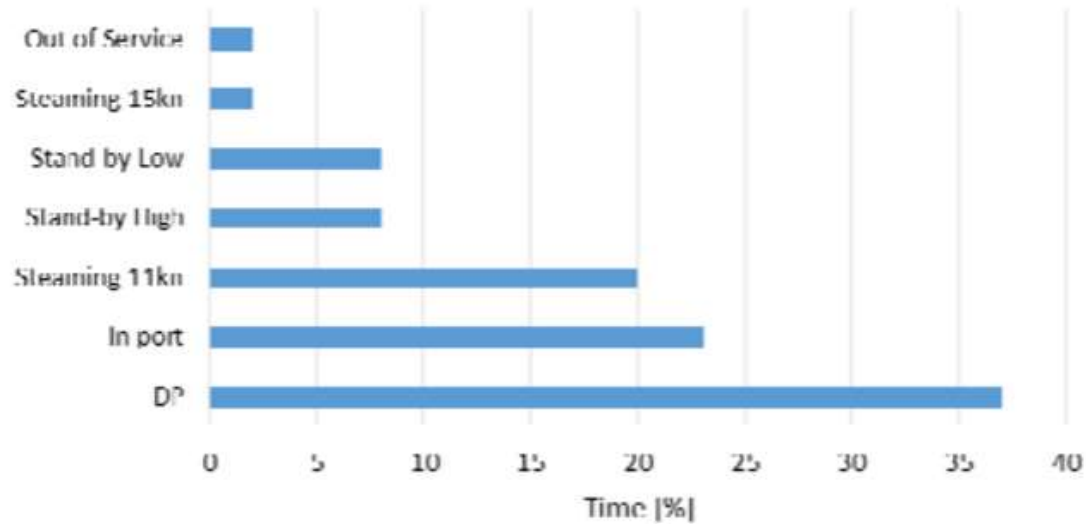


Dynamic Positioning (DP)



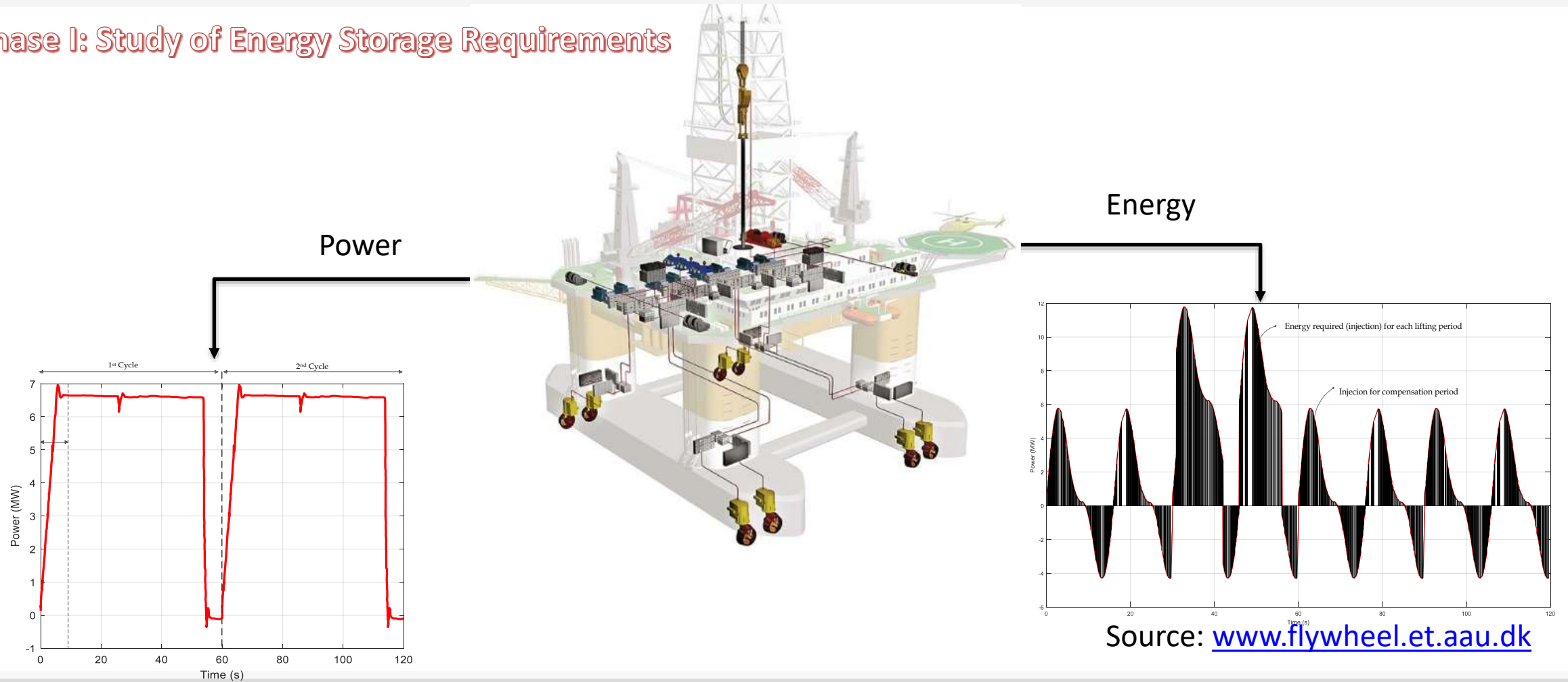
Source: Pirie & Smith, Ltd, UK

Typical Operation Profile



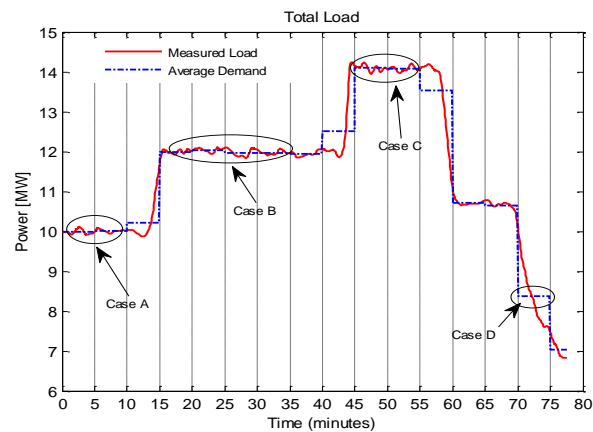
| Mode | Time [%] | Power Demand [kW] |
|----------------|----------|-------------------|
| DP | 37 | 2128 |
| In port | 23 | 168 |
| Steaming 11kn | 20 | 1836 |
| Stand-by High | 8 | 1000 |
| Stand-by Low | 8 | 755 |
| Steaming 15kn | 2 | 4260 |
| Out of Service | 2 | 0 |

Phase I: Study of Energy Storage Requirements



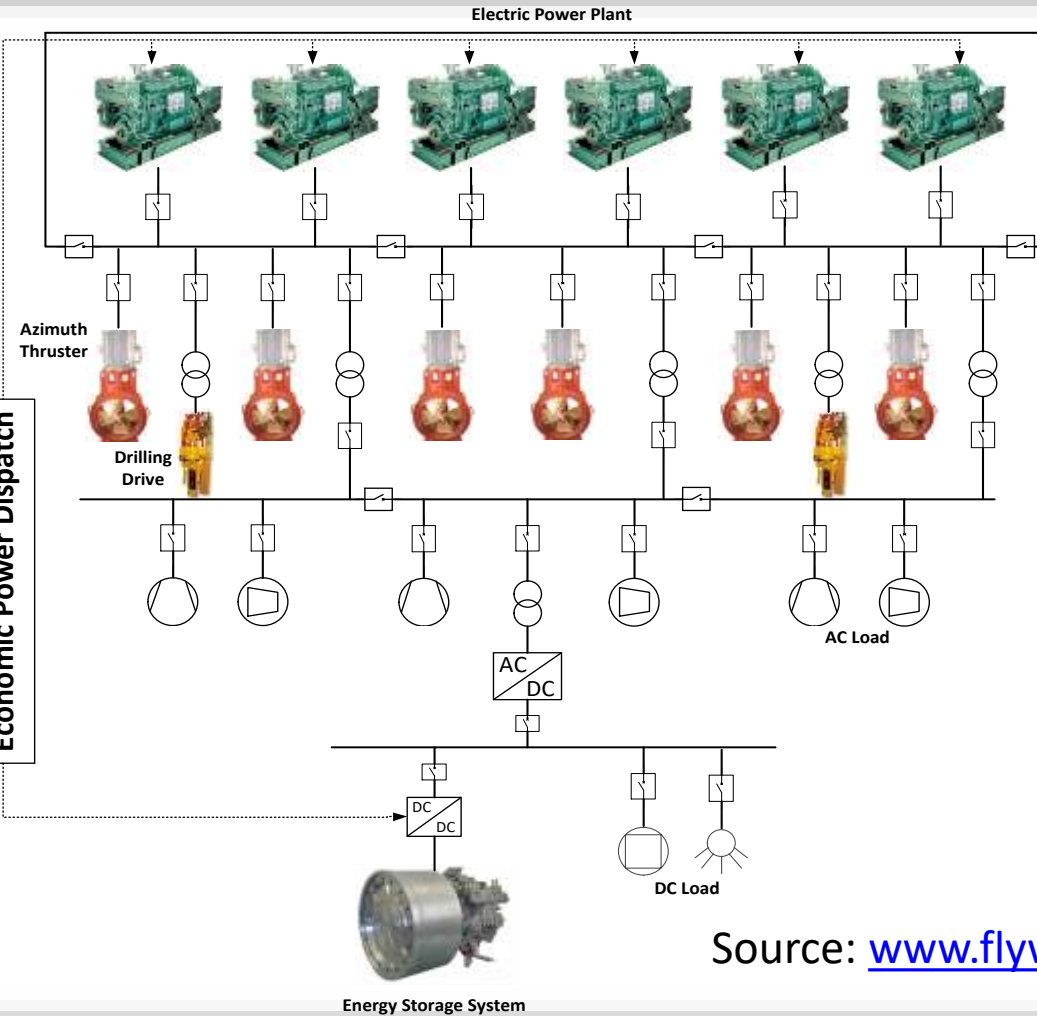
Source: www.flywheel.et.aau.dk

Phase II: Optimal Operation Management

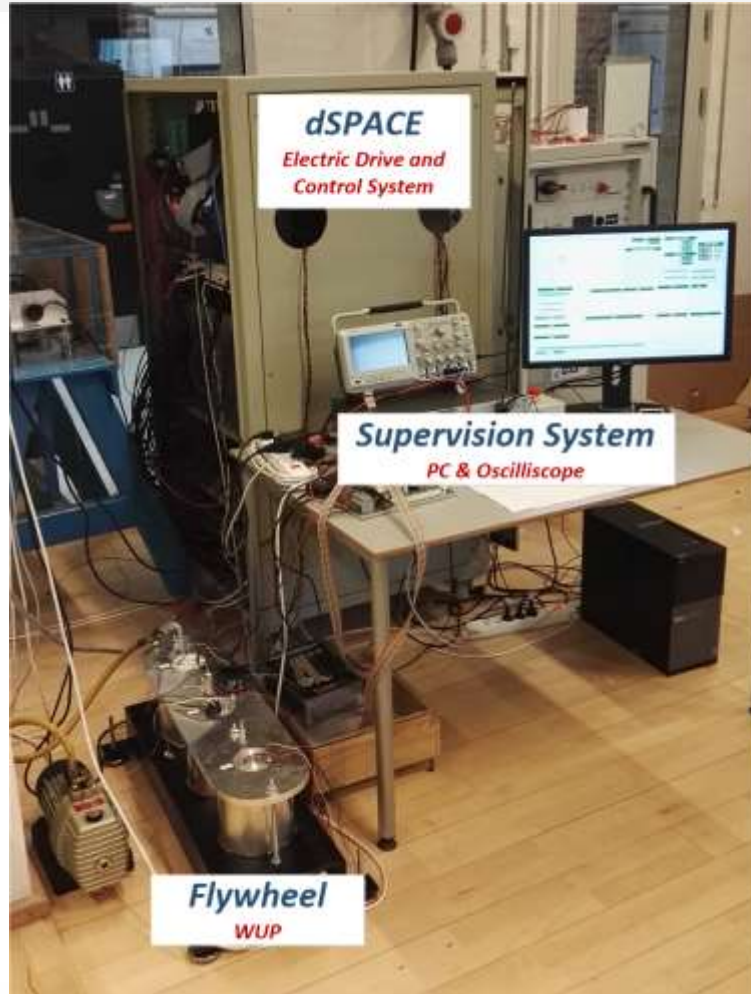


System Load
Mission Profile
Shipboard Section
Plant Configuration
Units Specifications

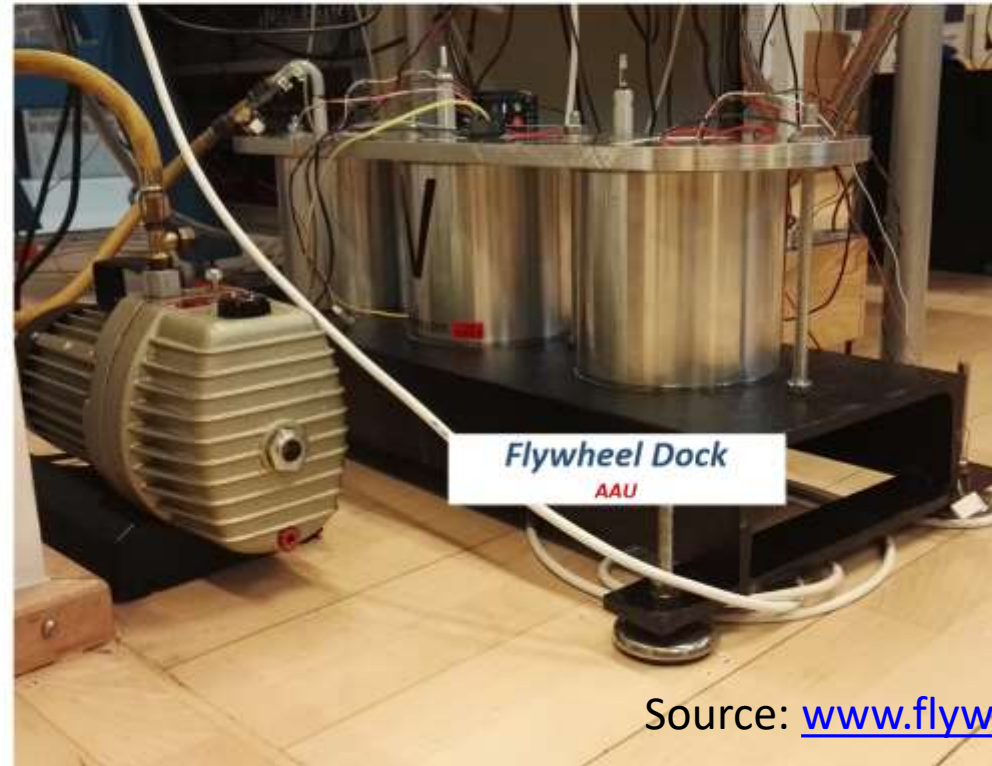
Economic Power Dispatch



Source: www.flywheel.et.aau.dk



Phase III: HIL Test and Validation



Source: www.flywheel.et.aau.dk

New release: 30 kWh Flywheel

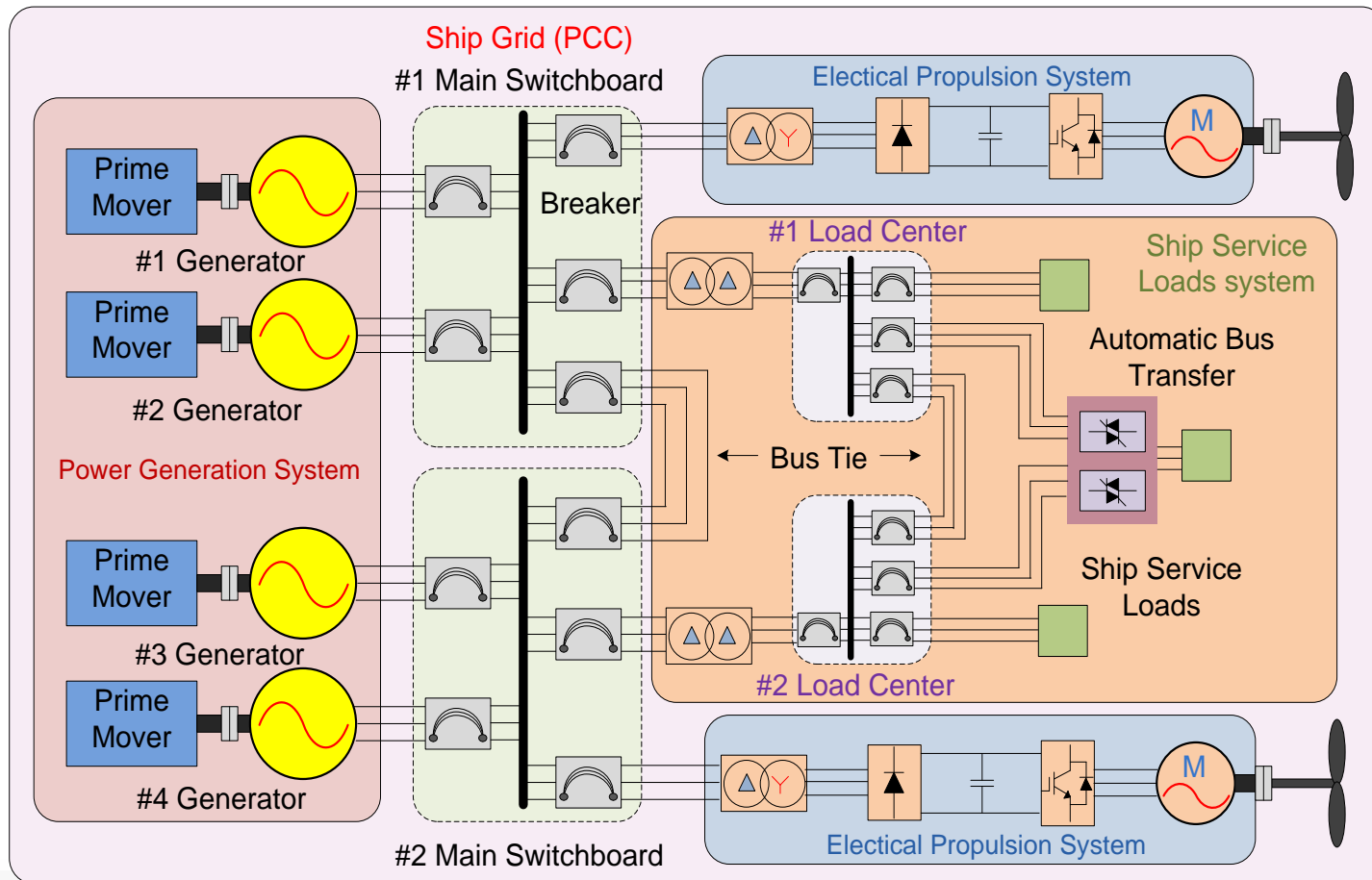


Source: WattsUpPower

- State-of-the-art and trends in SPS
- AC-DC grids in SPS
- ESS integration
- Power Quality Issues in SPS
- Cold-Ironing

- State-of-the-art and trends in SPS
- AC-DC grids in SPS
- ESS integration
- Power Quality Issues in SPS**
- Cold-Ironing

AC Maritime Microgrid Systems



PQ issues

(steady/ transient)

Harmonic/Inter-harmonic

Unbalanced Waveforms

Frequency Variation

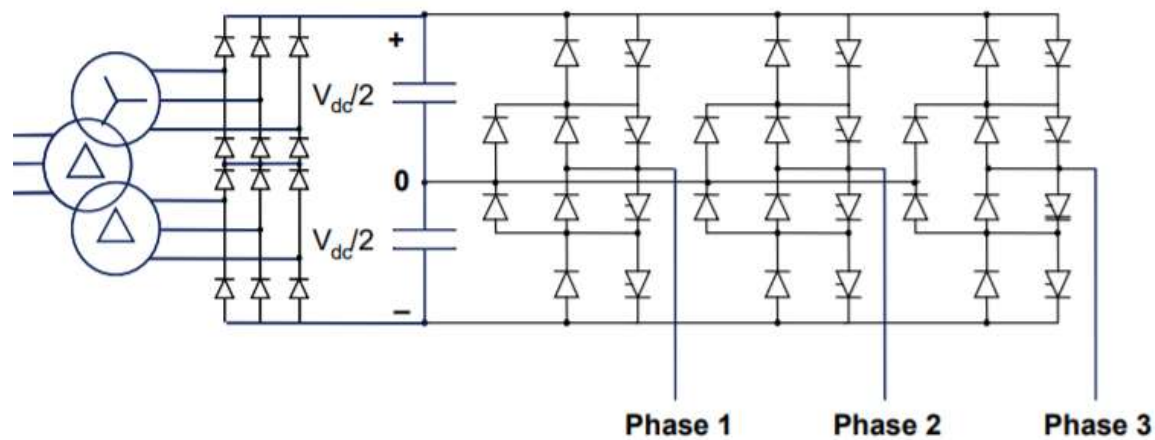
Power oscillations

**Flickers, Notching
and Fluctuation**

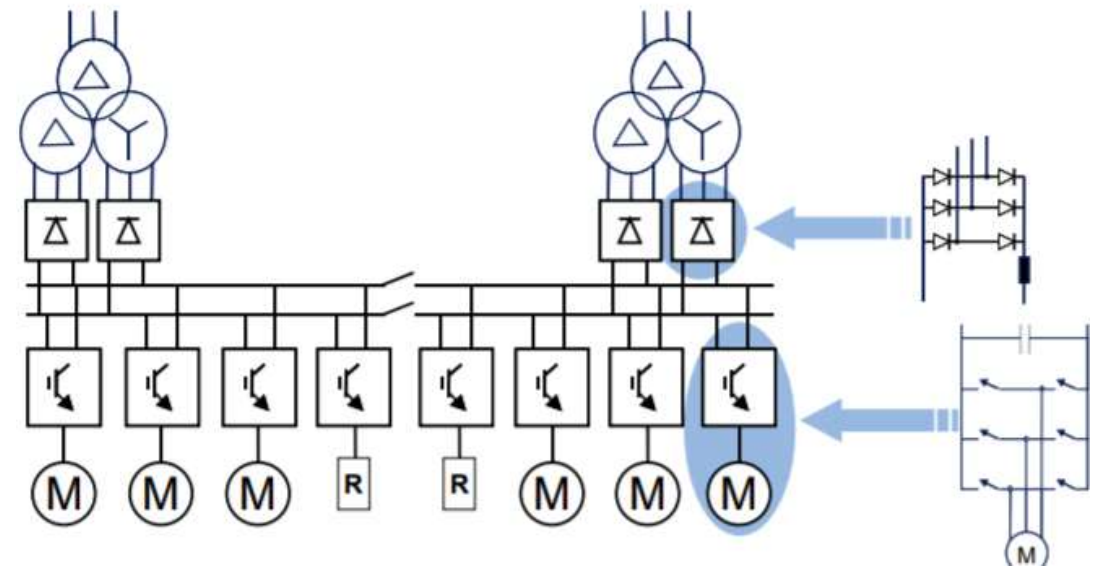
**Power flow/Power sharing
Protection**

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.

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% |

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



Ship



Engine room



Control board

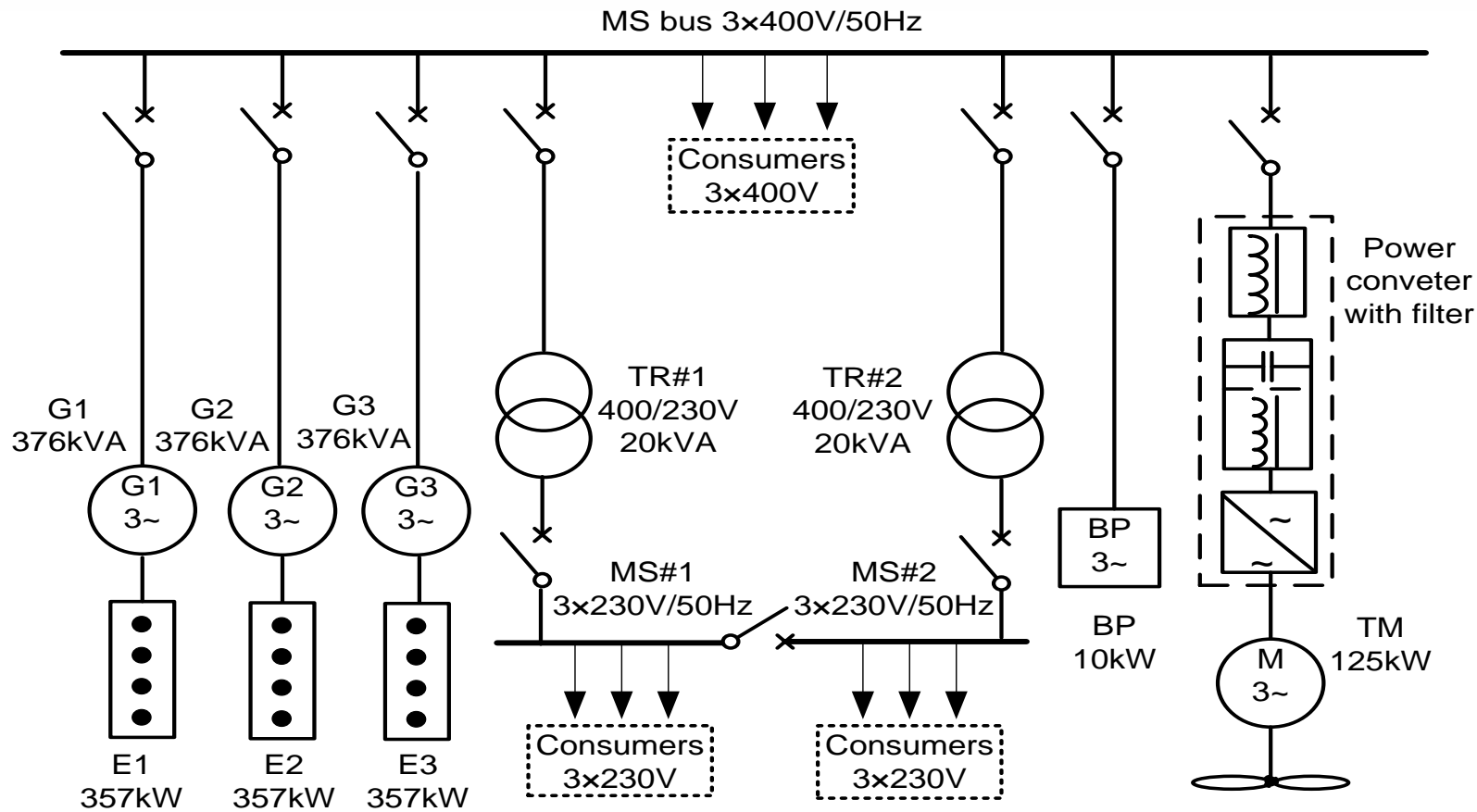


Diesel generator



Pump





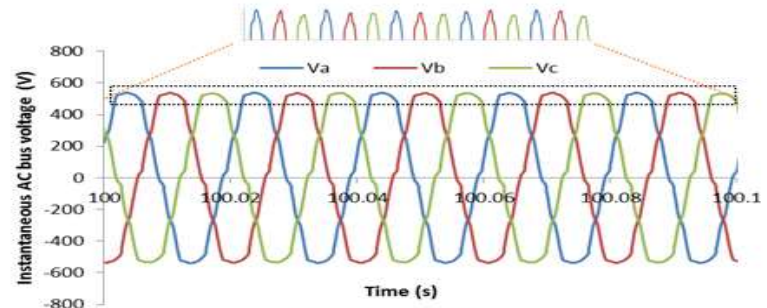
(2)

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

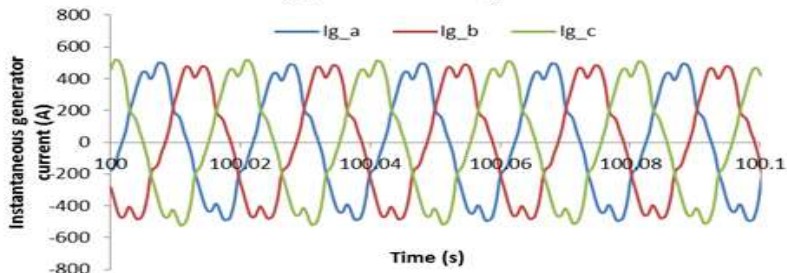
Comparison:

Balanced SPS

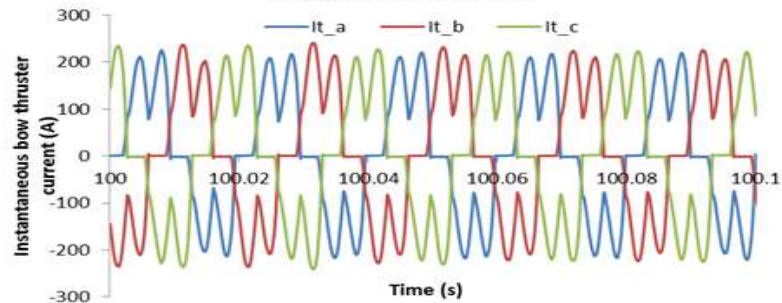
Slightly Unbalance SPS (UF=1.5%)



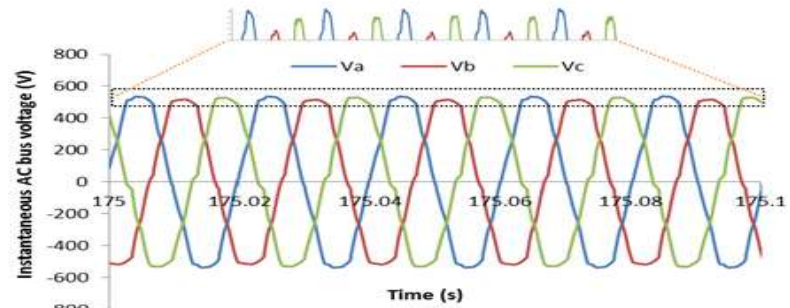
(a) AC bus voltage



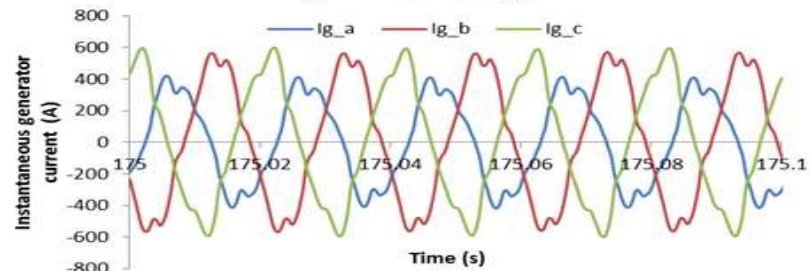
(b) generator current



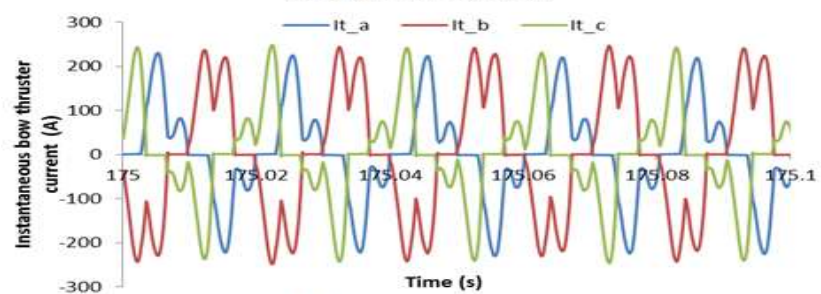
(c) bow thruster current



(a) AC bus voltage



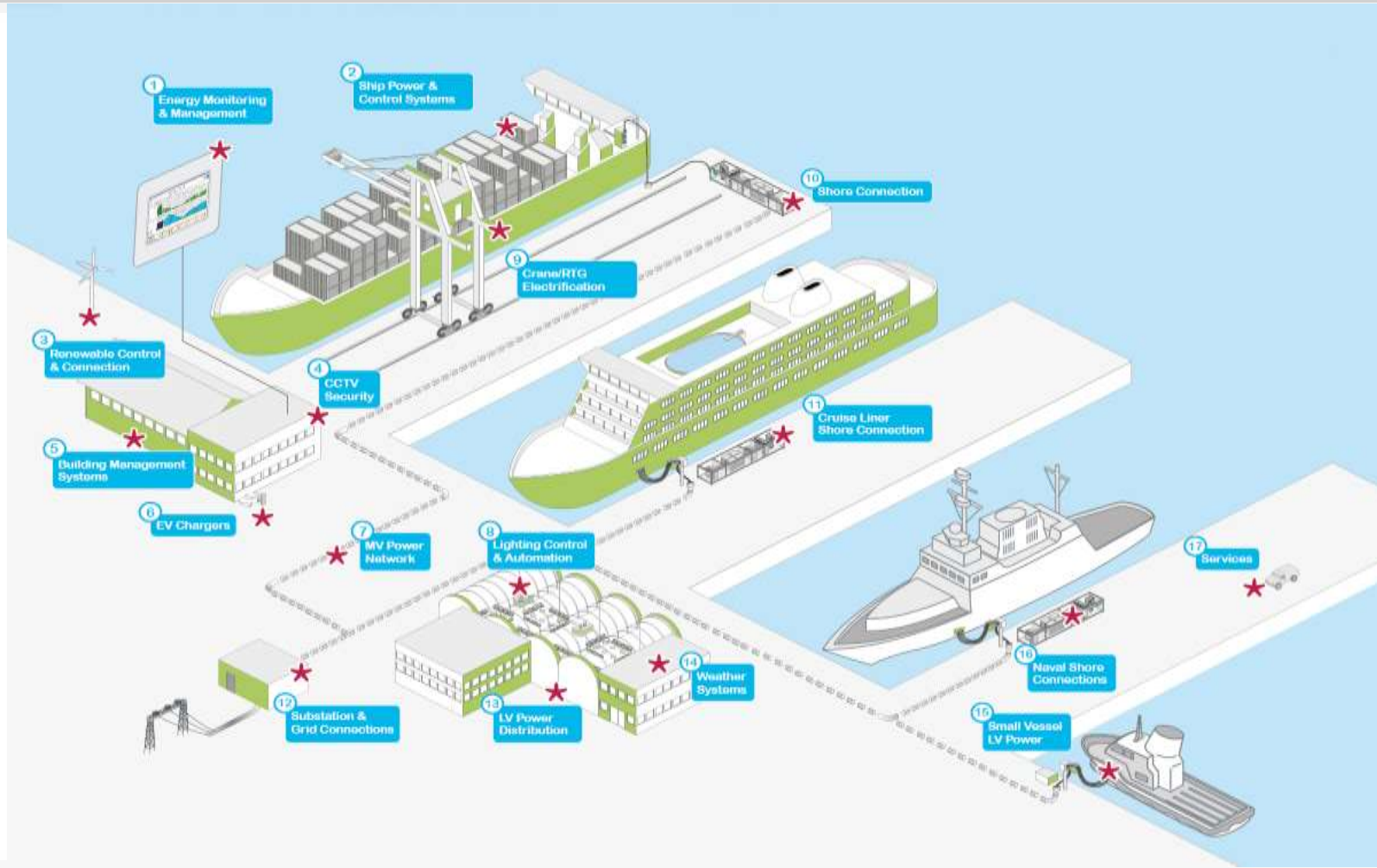
(b) generator current



(c) bow thruster current

- State-of-the-art and trends in SPS
- AC-DC grids in SPS
- ESS integration
- Power Quality Issues in SPS
- Cold-Ironing

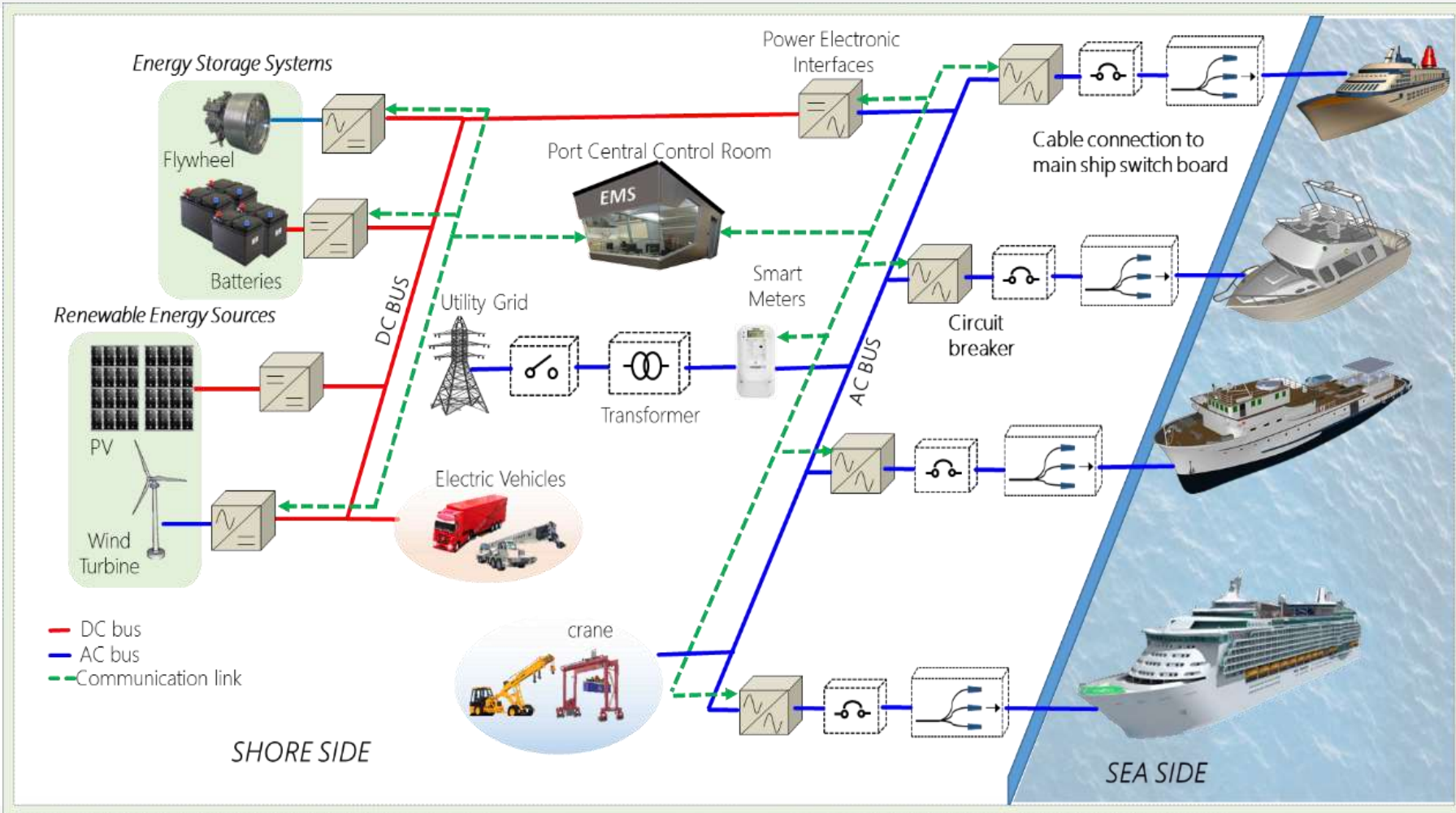
- State-of-the-art and trends in SPS
- AC-DC grids in SPS
- ESS integration
- Power Quality Issues in SPS
- Cold-Ironing**



Vessel shore
power
connection

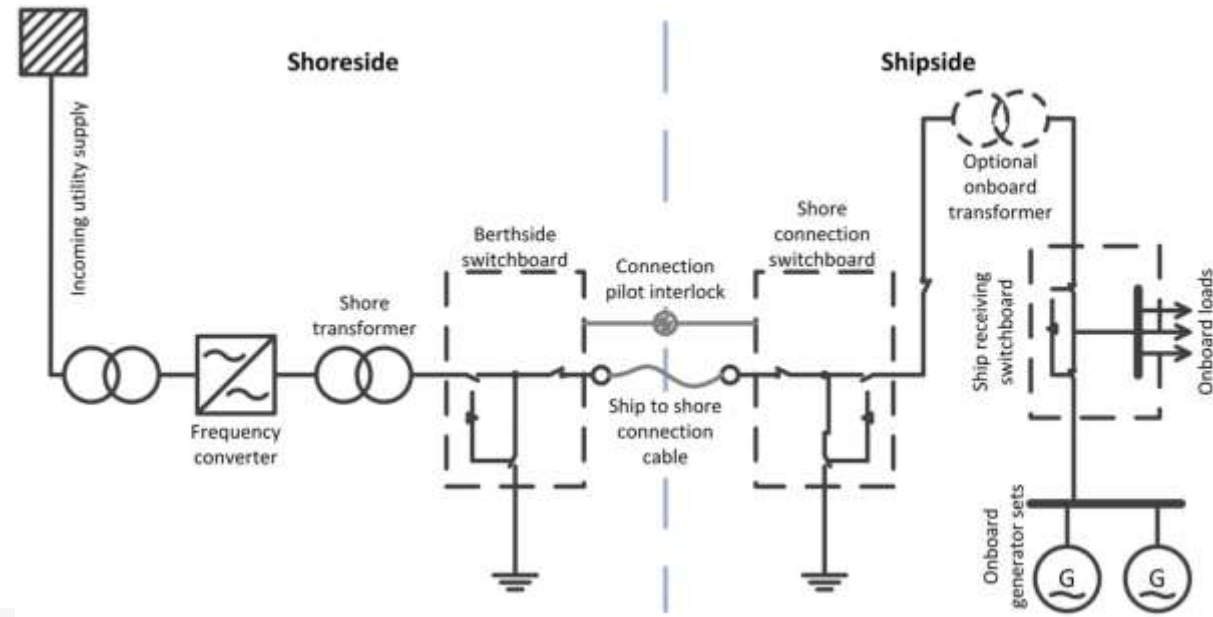
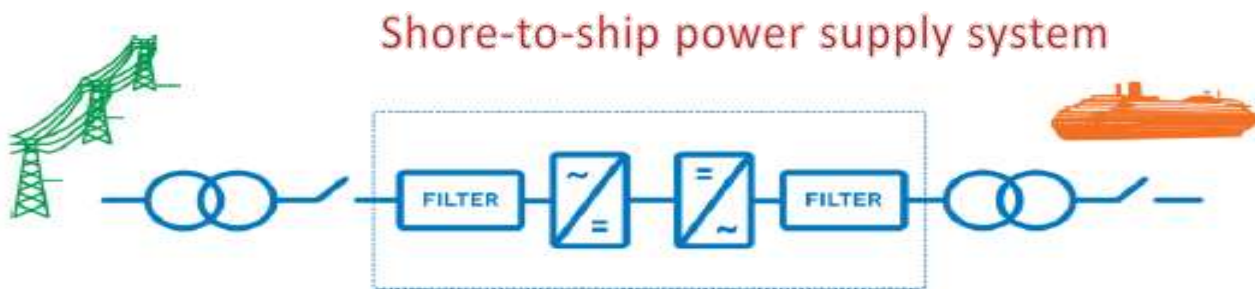
LV & HV
Plug and Play
solutions

Seaports



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

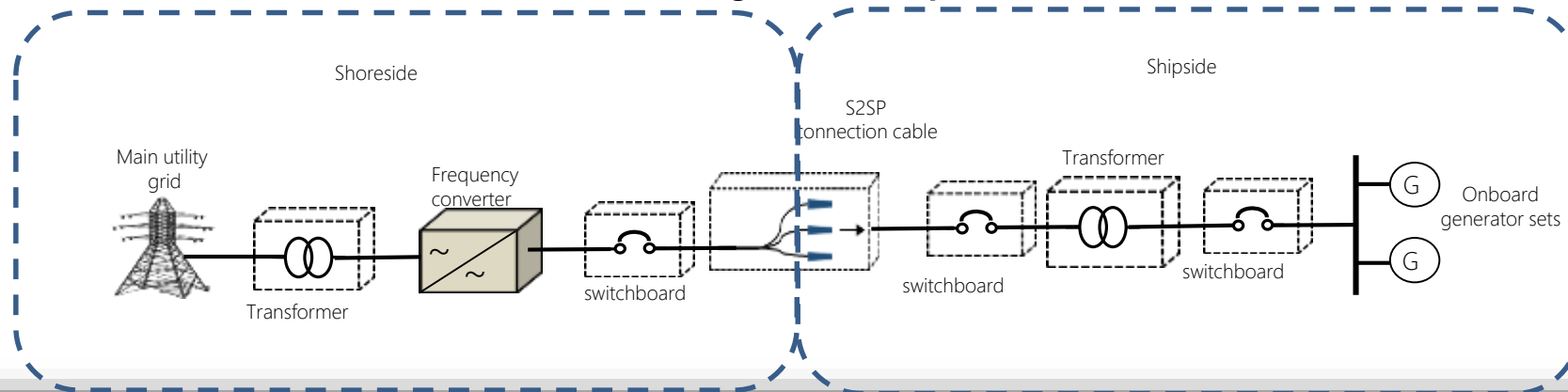


Source: Vacon Power / Danfoss

Cold Ironing

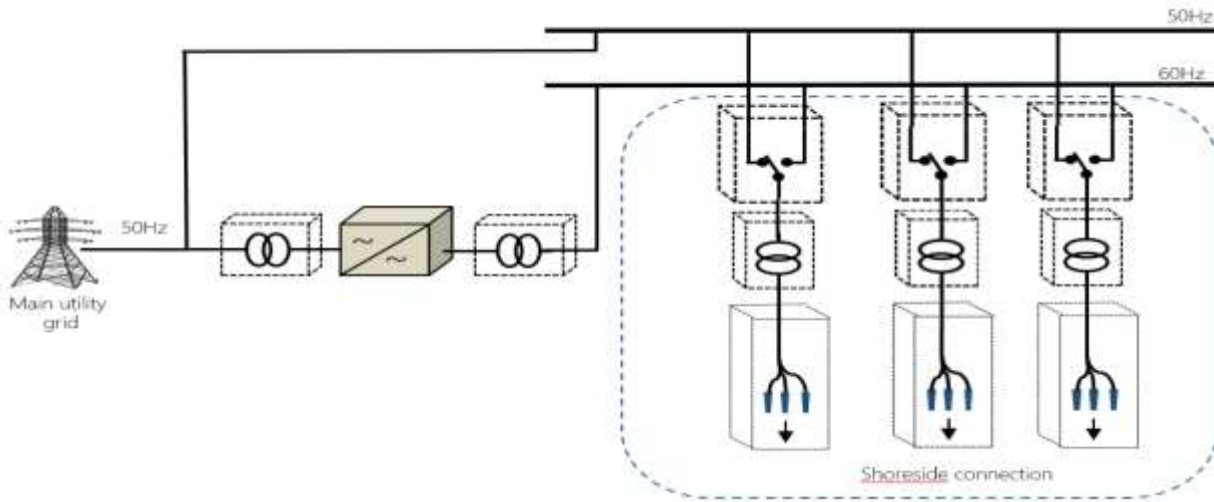


Generic cold ironing standard requirement



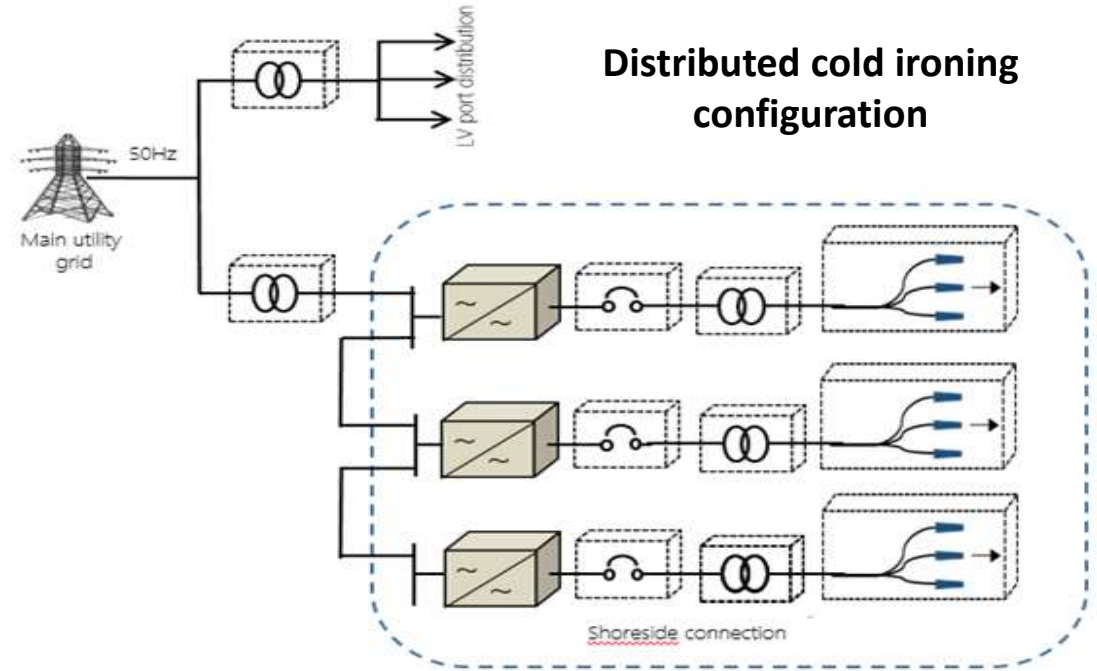
Cold Ironing

Centralised cold ironing configuration



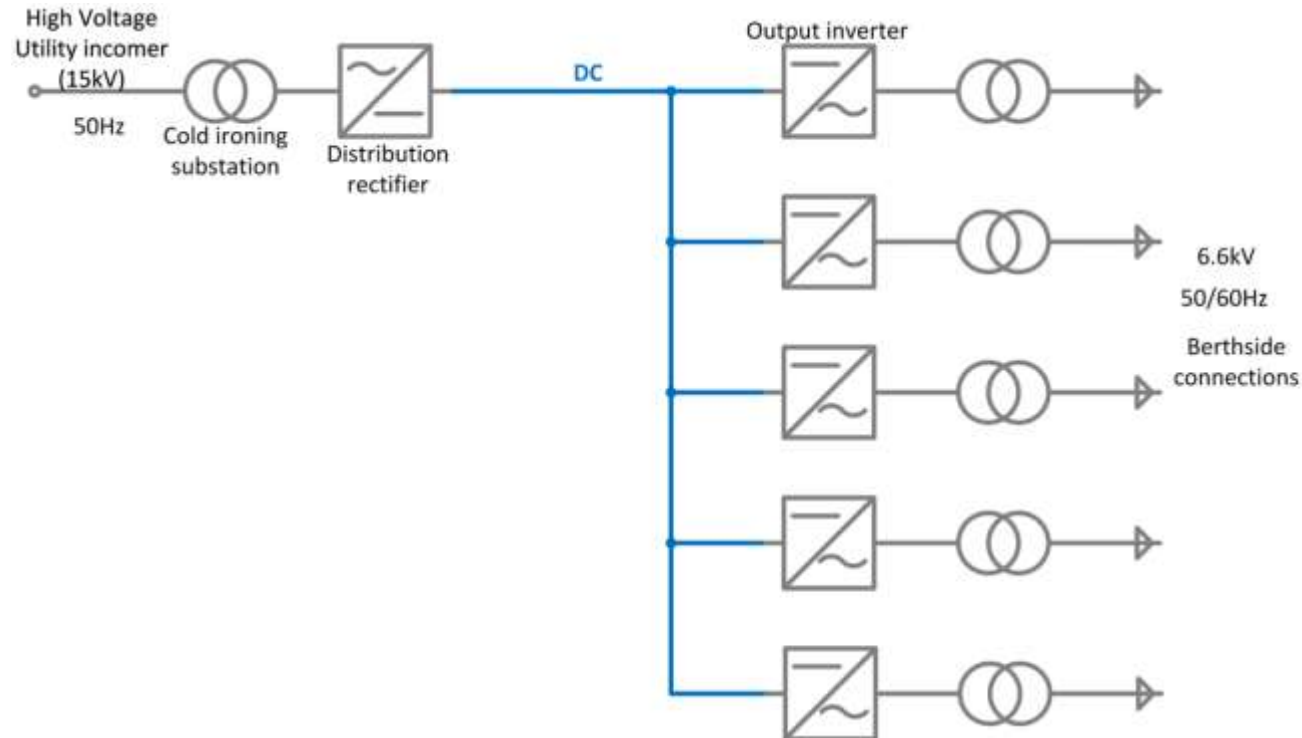
- Used one frequency converter as a central and double busbar to allowed the ship berthing either 50Hz or 60Hz.

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

DC distribution configuration



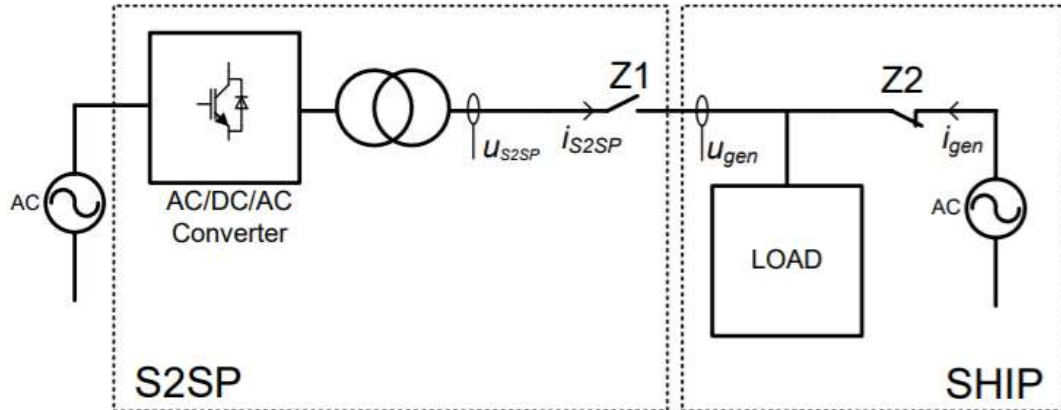
- By extending of two previous configuration with introducing DC bus.
- Easier to integrate with any energy storage device
- Able to use in small quay area

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.

Synchronization

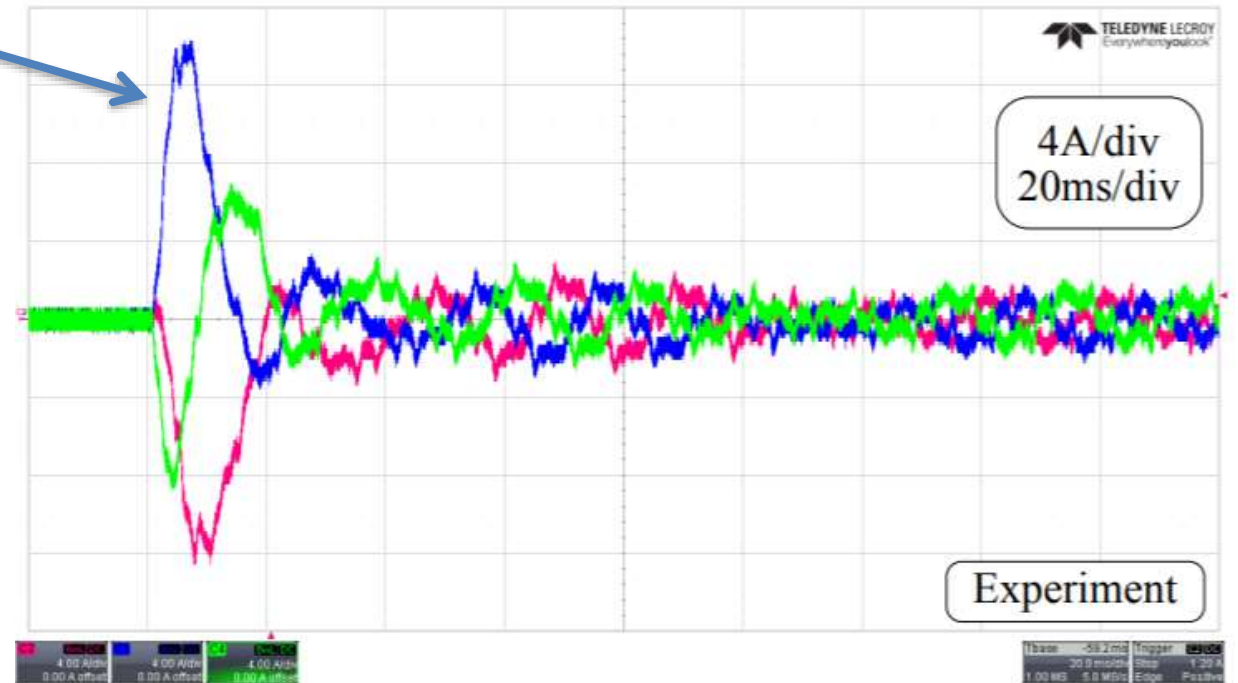
If Ship tries to synchronize bulky DG with the shore, huge inrush currents appear due to inertia

Simplified block scheme of S2SP system



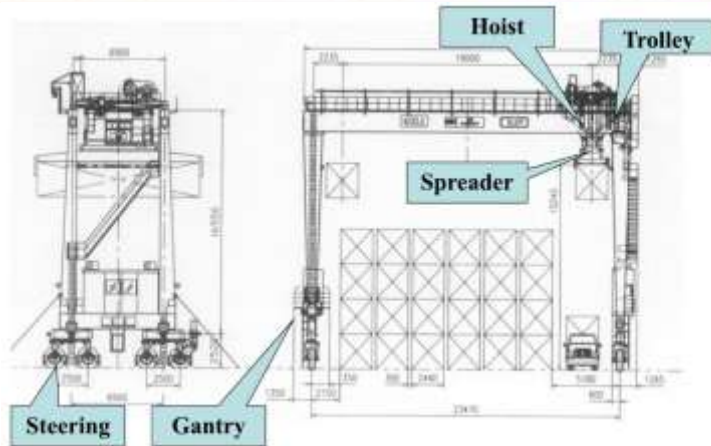
SP2S case

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

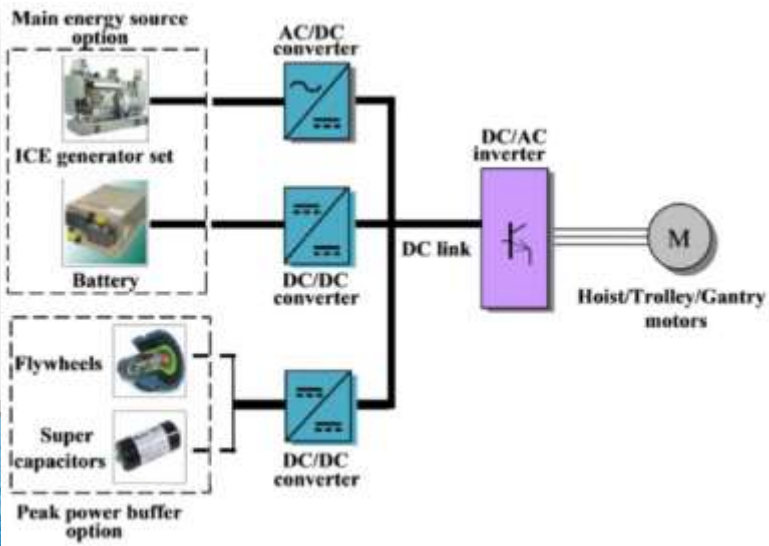
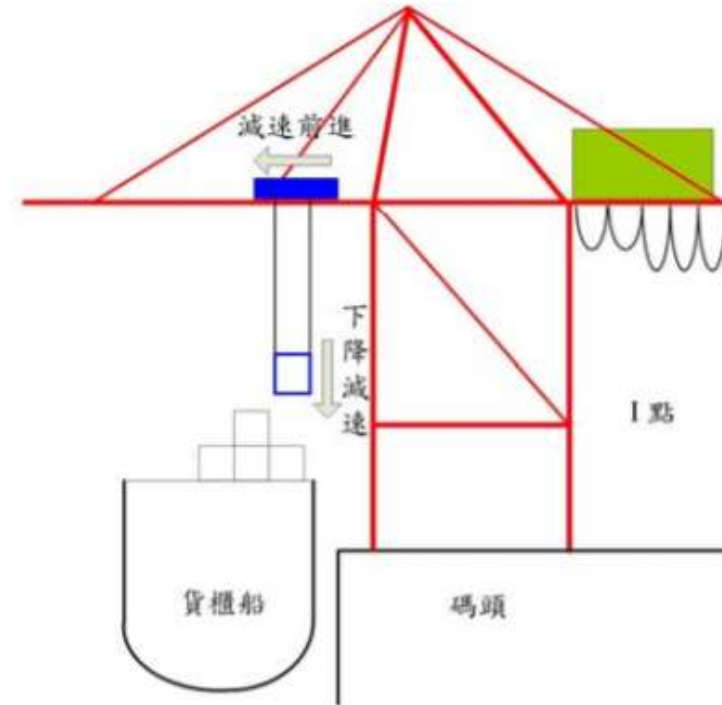
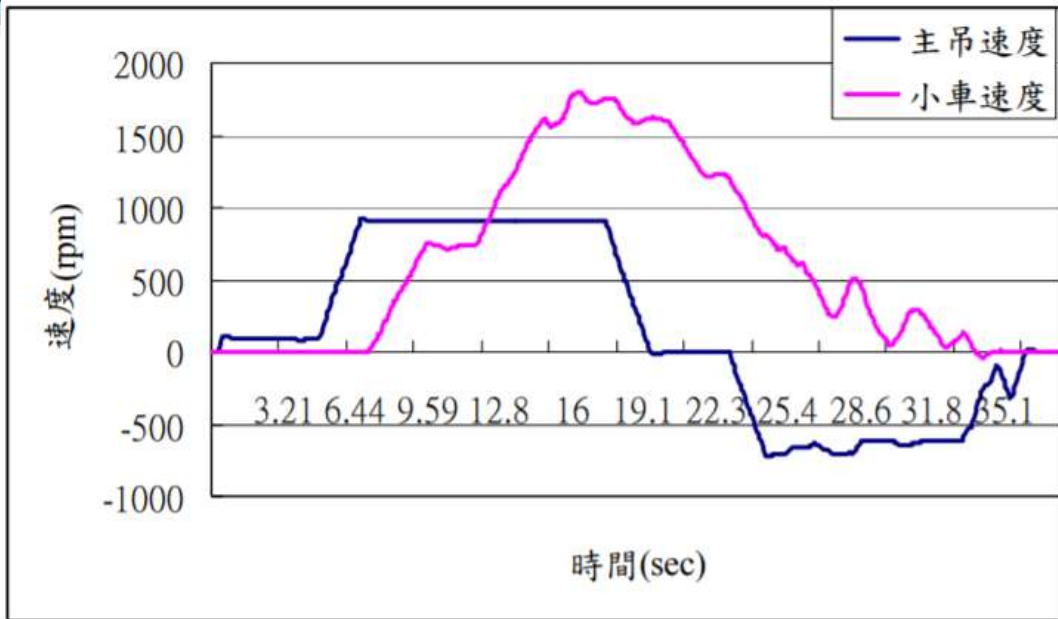


Source: *Ship-to-Shore vs. Shore-to-Ship Synchronization Strategy*, R. Smolenski, et al., IEEE TEC, 2018

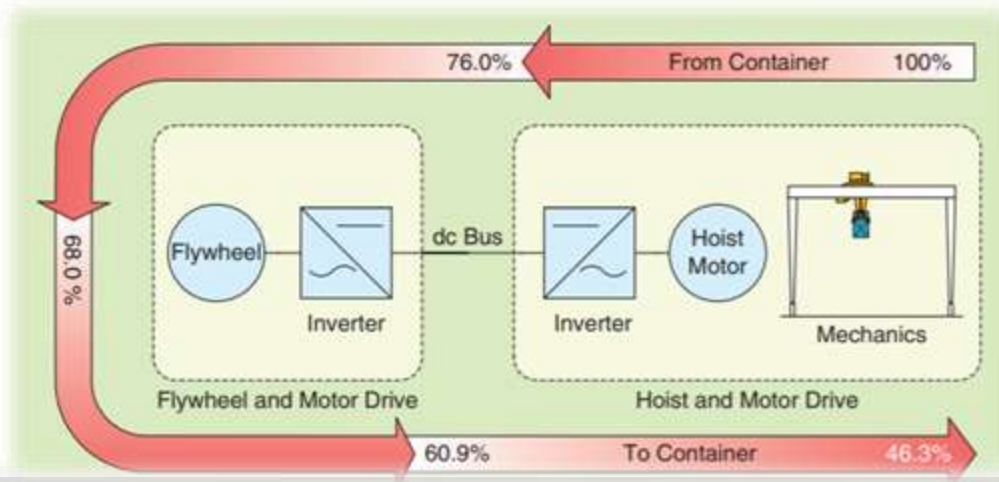
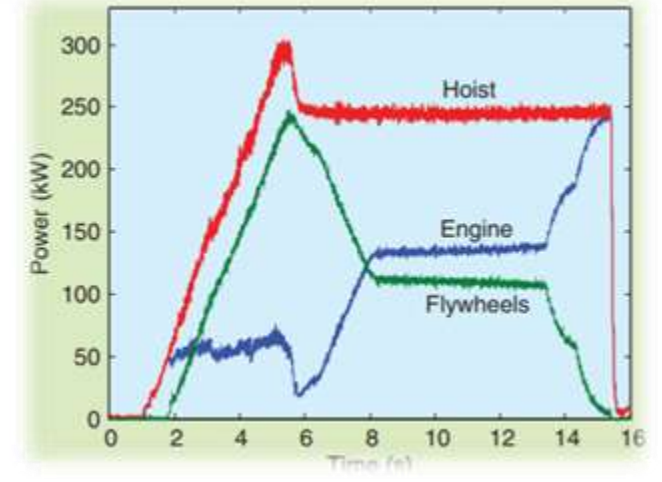
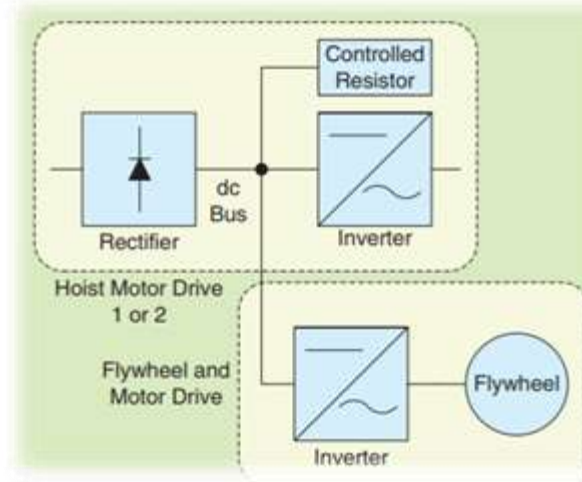
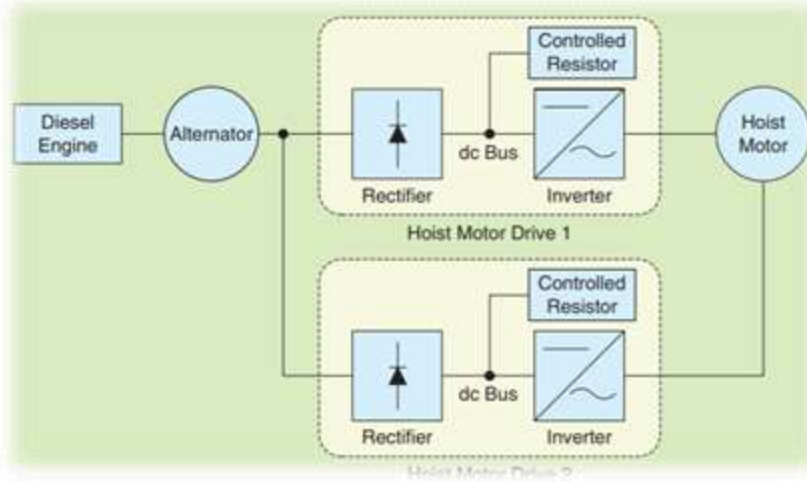
Port Cranes



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



- +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 magazine* 14.6 (2008).



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Ongoing PhD maritime projects



- Integration of Microgrid Technologies In Future Seaports - Nor Baizura Binti Ahamad
- Energy Management System in Shipboard Microgrids - Muzaidi Bin Othman
- Maritime DC Microgrid Based On-Board Power System - Zheming Jin
- Power Electronics and Power Quality in Maritime Microgrids Systems - Wenzhao Liu
- Improving the Power Quality Issues of Shipboard Power Systems - Yacine Terriche



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Thank you!

For contact/cooperation:
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OF TRIESTE



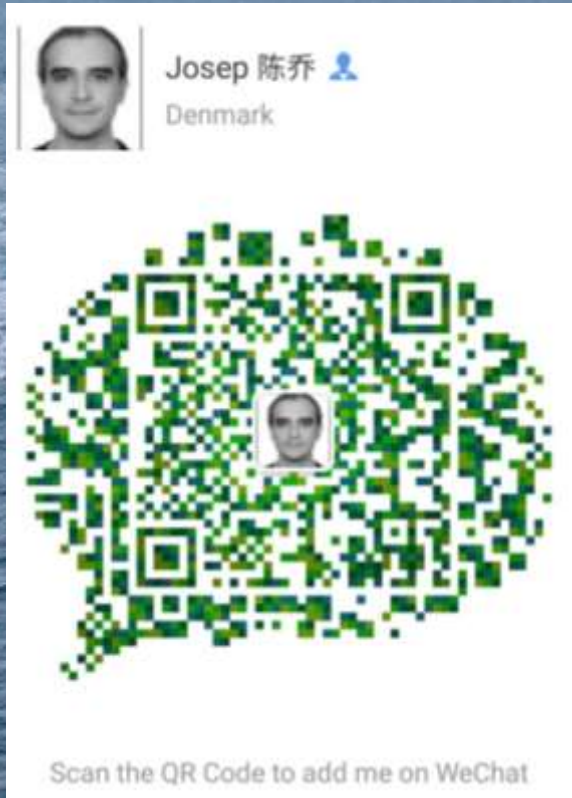
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We Chat: JG2037



A WeChat contact card for Josep M. Guerrero. It includes a profile picture of a man, his name "Josep 陈乔" with a blue verified account icon, and "Denmark" below it. A large, circular QR code is centered on the card, with a small profile picture of the same man overlaid on it. At the bottom of the card, it says "Scan the QR Code to add me on WeChat".

For contact/cooperation:
Josep M. Guerrero joz@et.aau.dk



Thank you!

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