
# New Research Challenges in Industrial and Residential Microgrids

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***Microgrid Research programme: www.microgrids.et.aau.dk***

# 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!

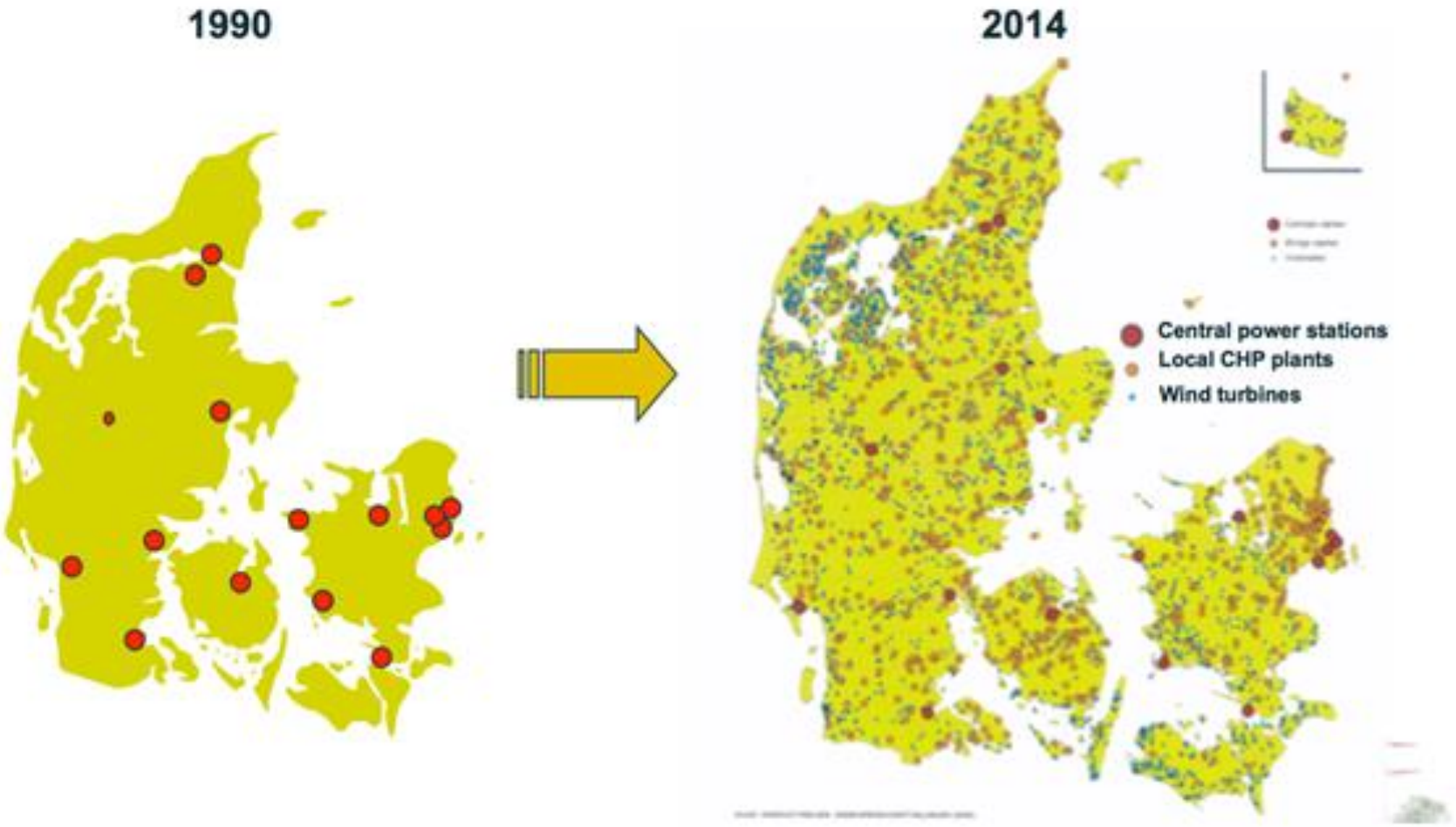
(again) it's a PI control!

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

# Real sentences from close people working in renewables (!):

- Are you crazy?
- I never consider PV as an investment
- Do you want to build a demo-house? Haha...
- But no sun in Denmark!
- Your EV is too confortable
- You have an EV, so which is your other car?
- Of course a hybrid one, right?
- Let me open the window to avoid discharge your batteries with the air condition
- You could buy a luxory car instead
- EV means that I have to change to many things
- Did you calculated the RoE?
- Yes, yes, nice... but this is imposible in my country.

# Denmark – Distributed generation paradigm

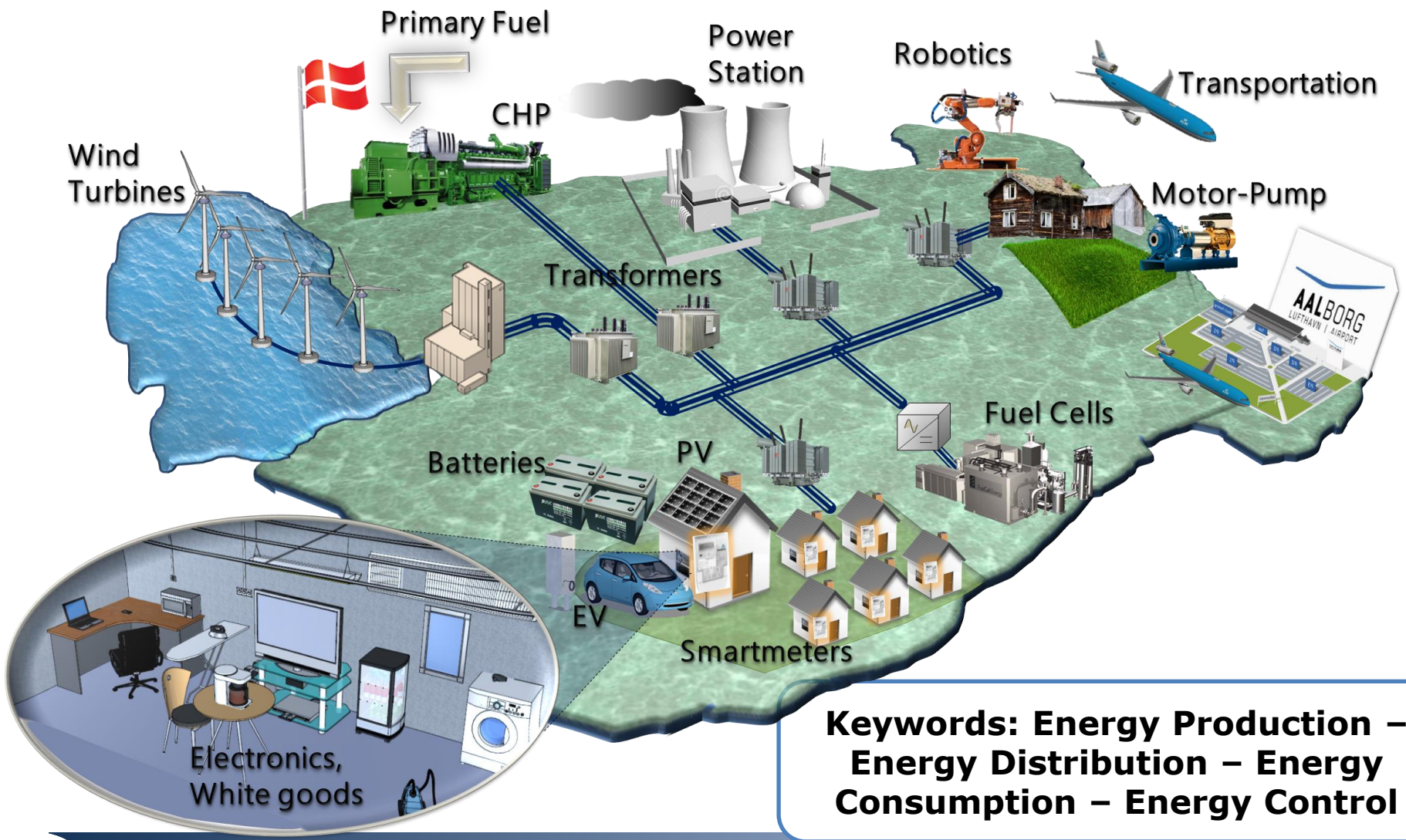


# Aalborg University

***Aalborg University*** was created with the establishment of a number of new faculties in **1974**.

Aalborg University is characterised by its education form of **Problem Based Learning (PBL)** – also known was the ***Aalborg model.*** The number of students is around 15,000.


# Institute of Energy Technology




**Keywords: Energy Production – Energy Distribution – Energy Consumption – Energy Control**

# MICROGRID RESEARCH PROGRAMME

## Programme Purpose

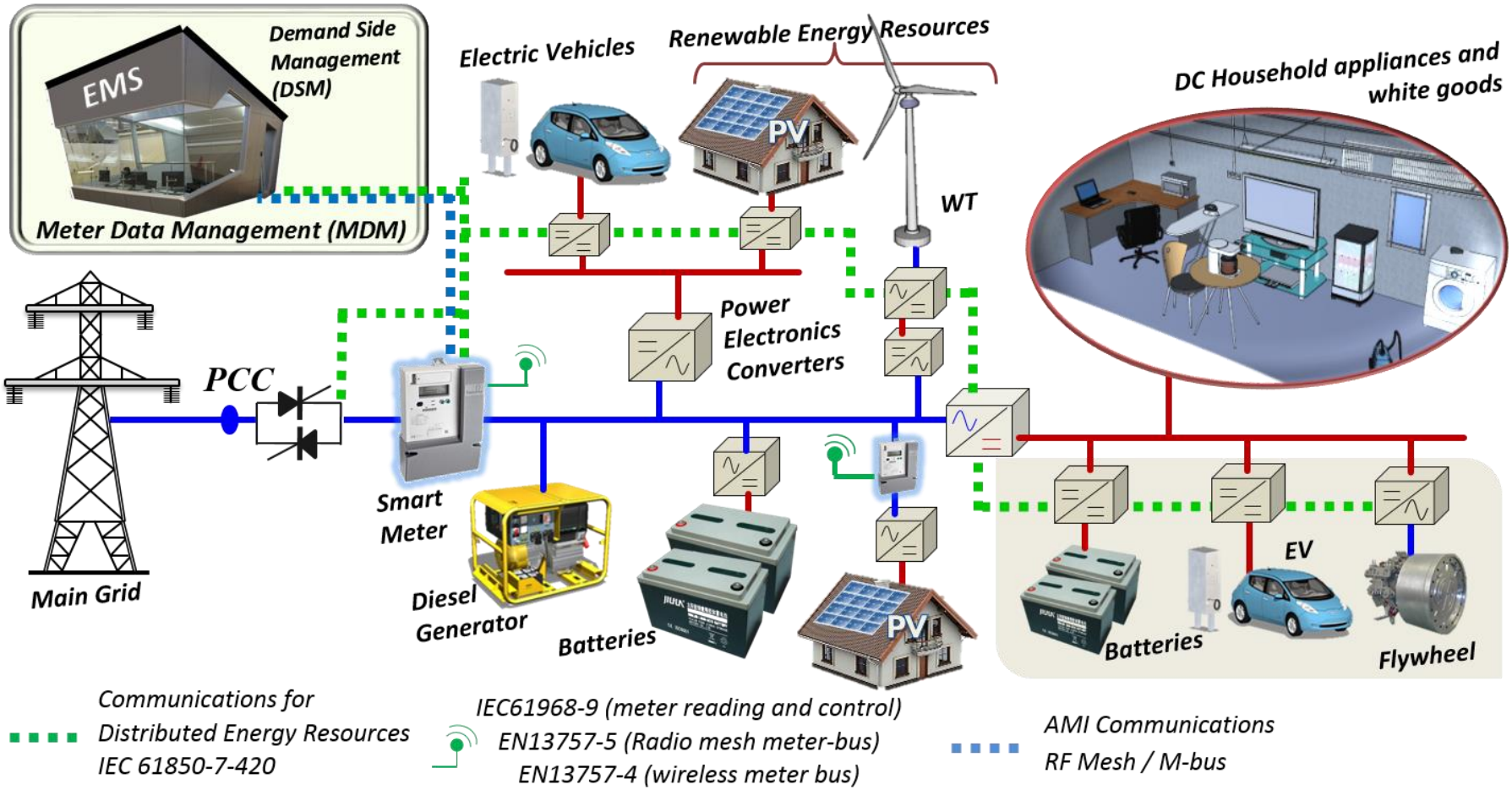
Microgrid Research Programme **Areas**

- **AC** Microgrids
- **DC** Microgrids

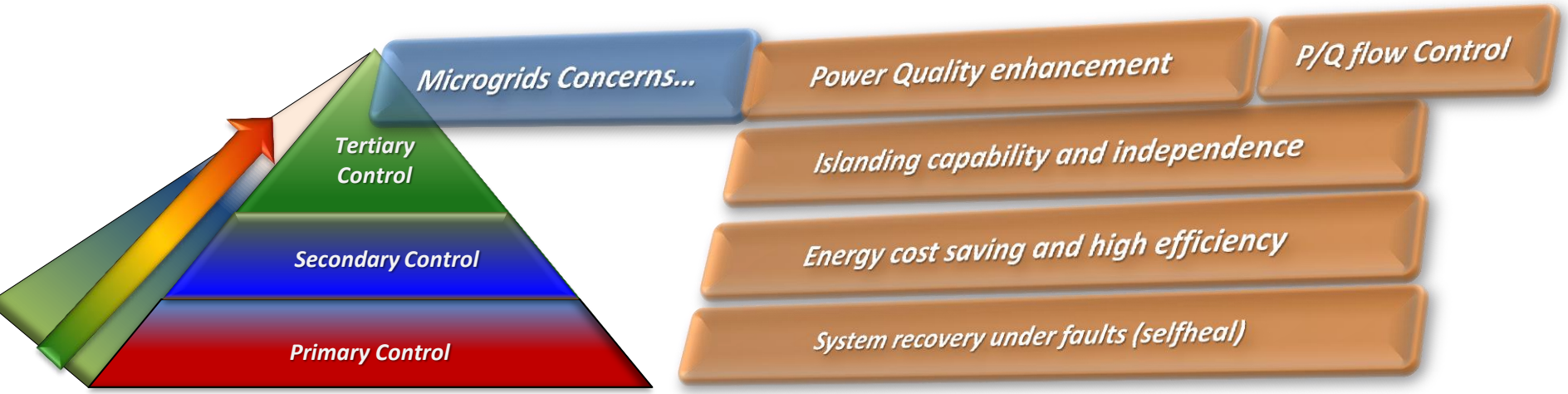
- ✓ Modeling, Control & Operation
- ✓ Energy Storage
- ✓ Protection
- ✓ Power Quality
- ✓ Standard-based ICT
- ✓ EMS & Optimization
- ✓ Multi-Agents

# MICROGRID RESEARCH TEAM

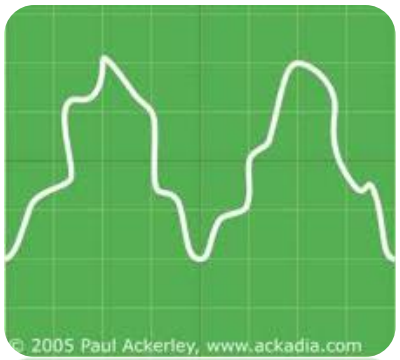
# Concept of Microgrid IEEE Std 1547.4



# Hierarchical Control for MicroGrids



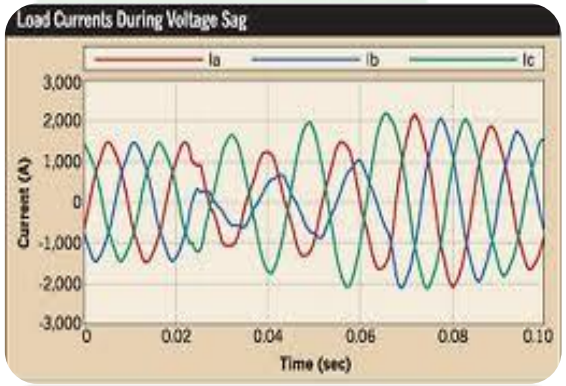
# Issues in MicroGrids: *Power Quality*




*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.***

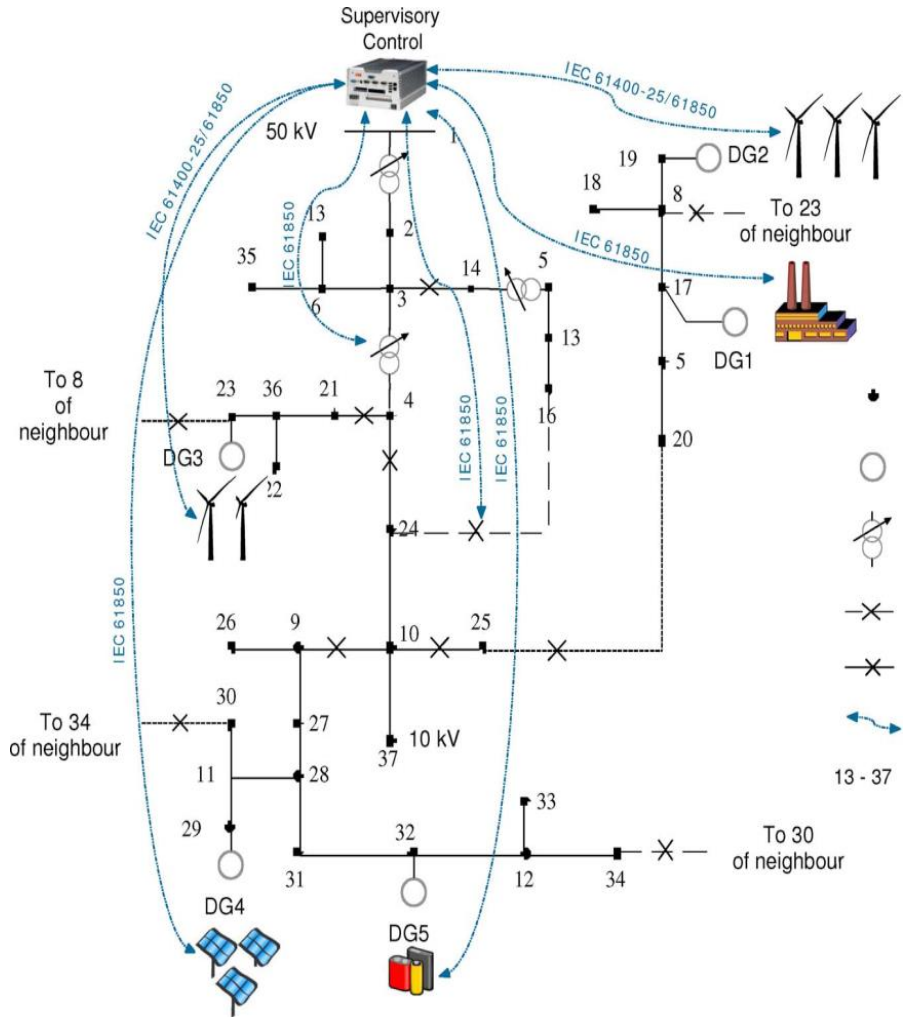
# How to Coordinate harmonic/unbalance compensation?

## The Whac-a-mole effect

**Primary control**
Harmonic virtual impedance

**Secondary control**
Harmonic/unbalance coordination control

# Issues in MicroGrids: *Communications*



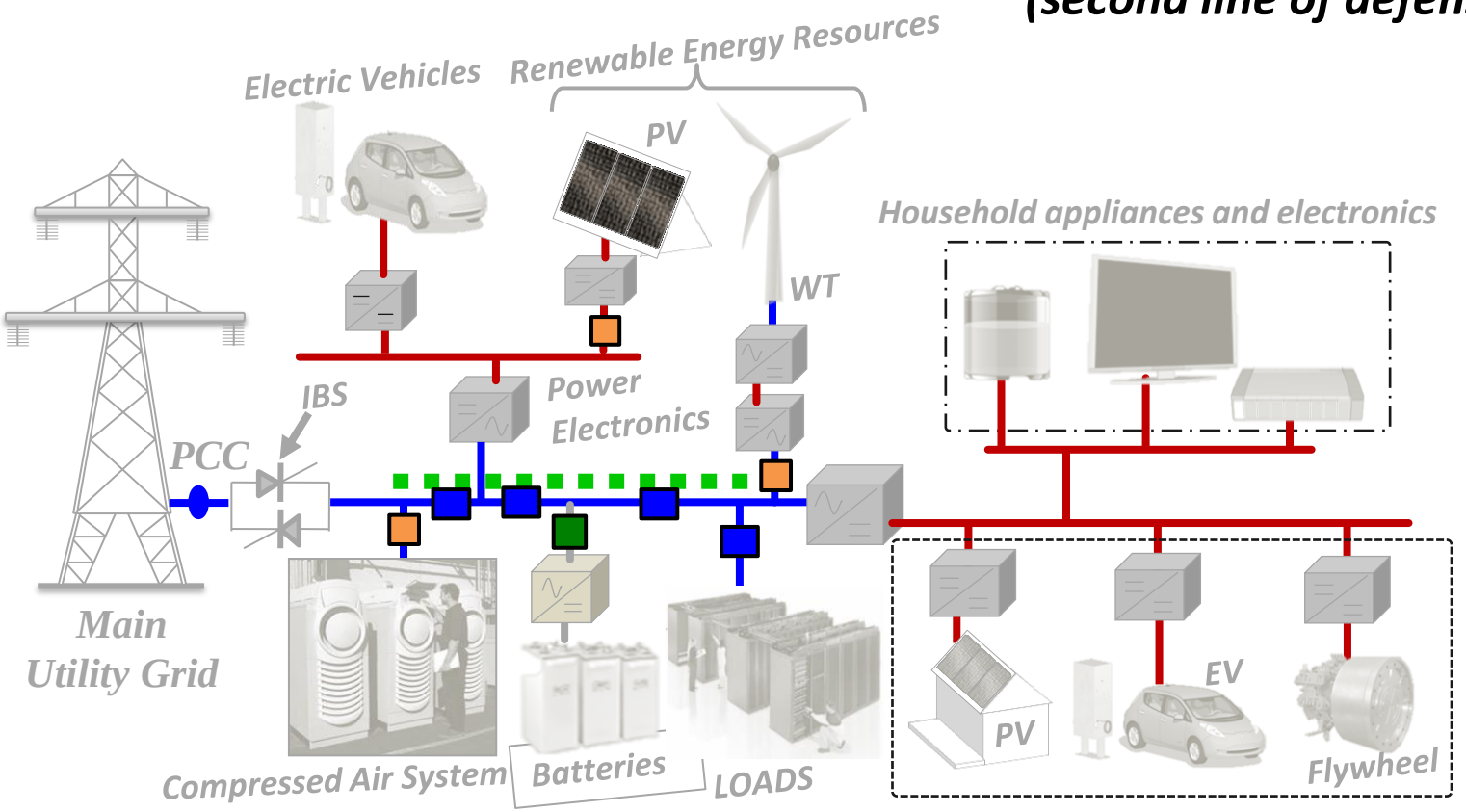

Communication model provided by ***IEC 61850 & IEC 61400-25*** to describe the physical devices in the network model.

- 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).

***Timbus et Al.*** *Management of DER Using Standarized Communications and modern Technologies*

# Issues in MicroGrids: *Protections*

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




***Source Protection*** ***Network Protection*** ***Bidirectional Protection***

# Microgrid Research Laboratory


MicroGrids
RESEARCH
PROGRAMME

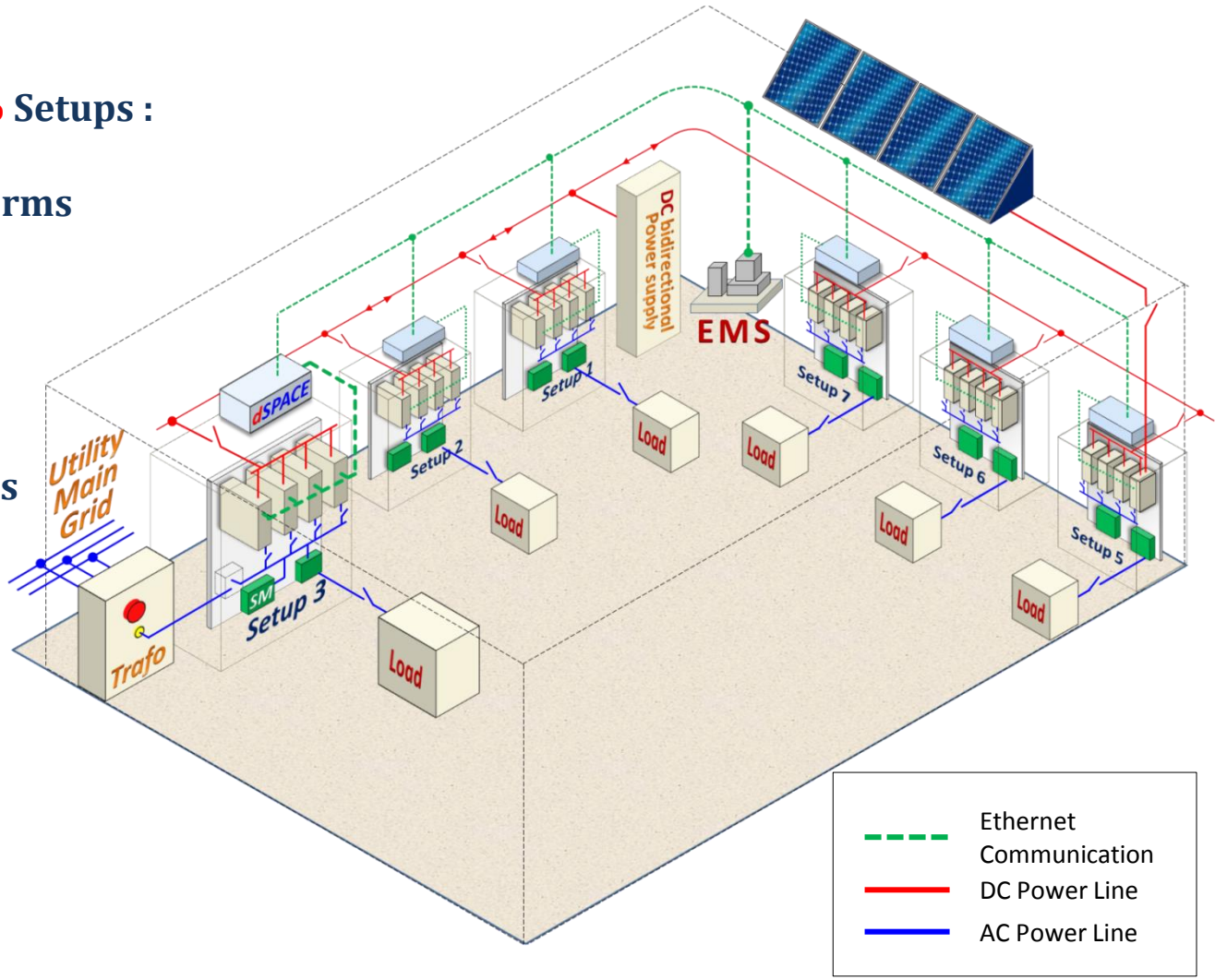
# Microgrid Research Laboratory

**Every setup is able to emulate a multi-converter low-voltage Microgrid, local and energy management control programmed in dSPACE real-time control platforms.**

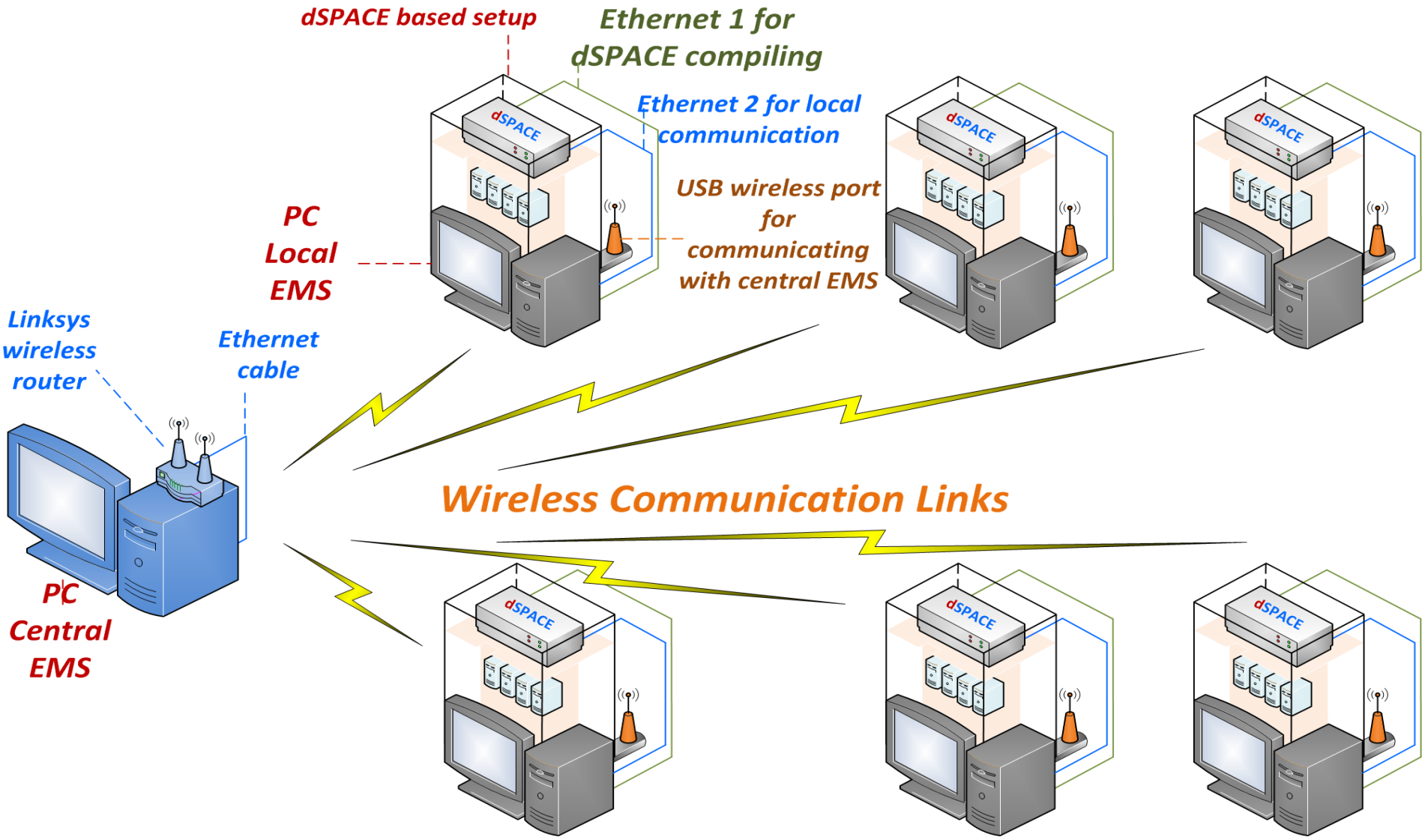

# Microgrid Research Laboratory

**The laboratory is based on 6 Setups :**

- **24 DC-AC converters**
- **6 real-time control platforms dSPACE**
- **L-C-L filters**
- **Change-over switches**
- **Smart-meters**
- **Transformers for Grid-connected applications**



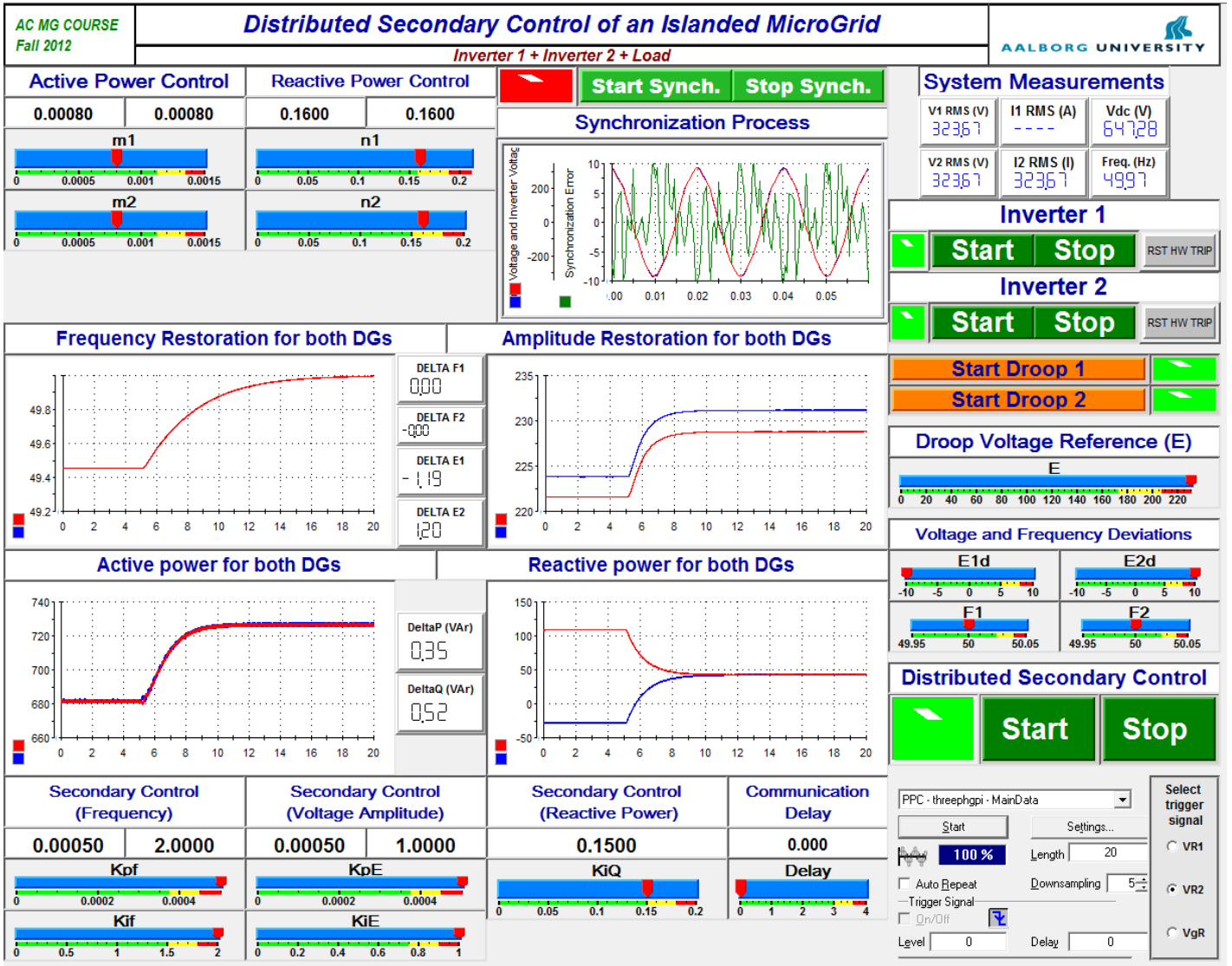
# Microgrid Research Laboratory



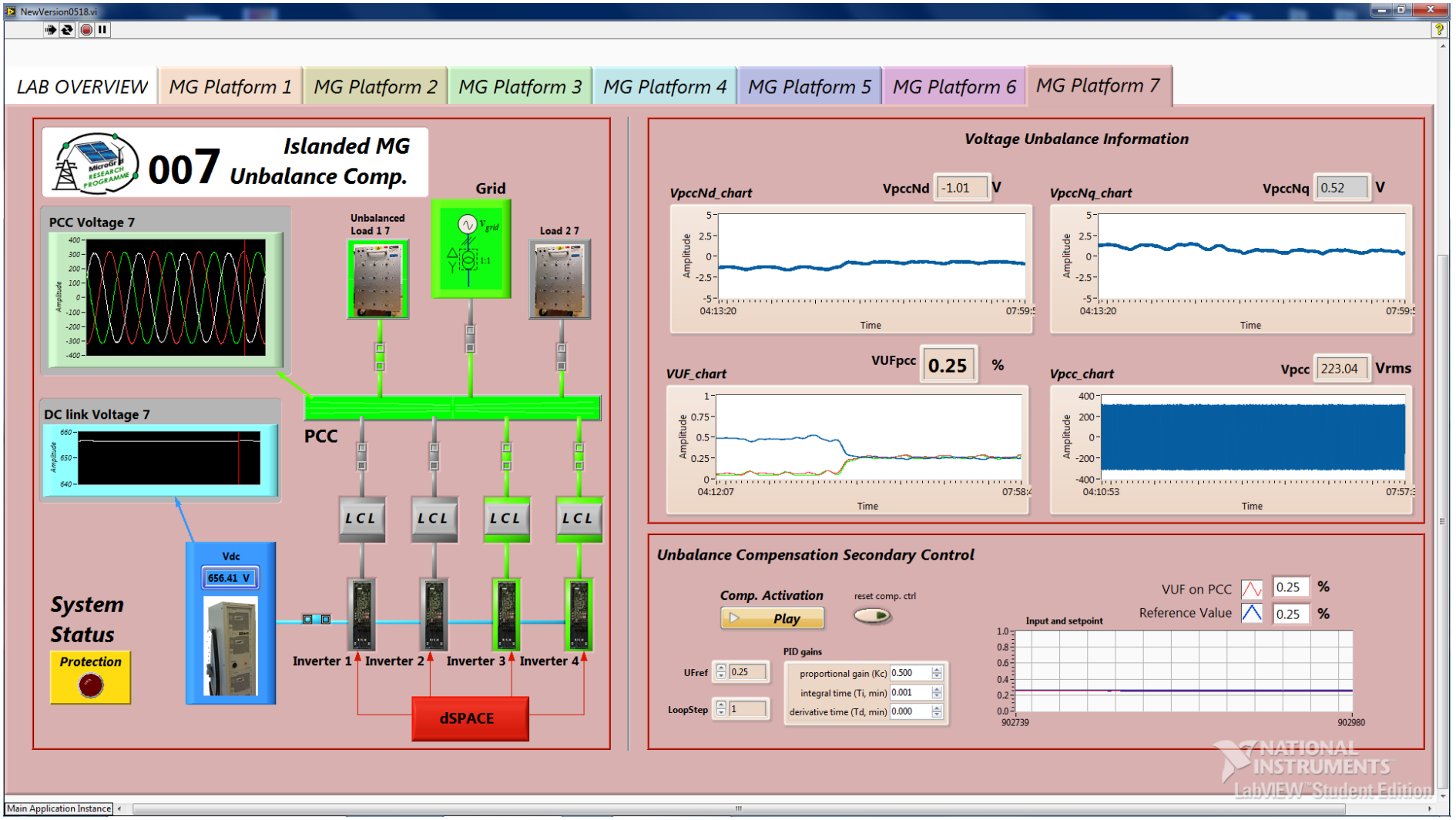
# Experimental test - DSPACE 1006

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

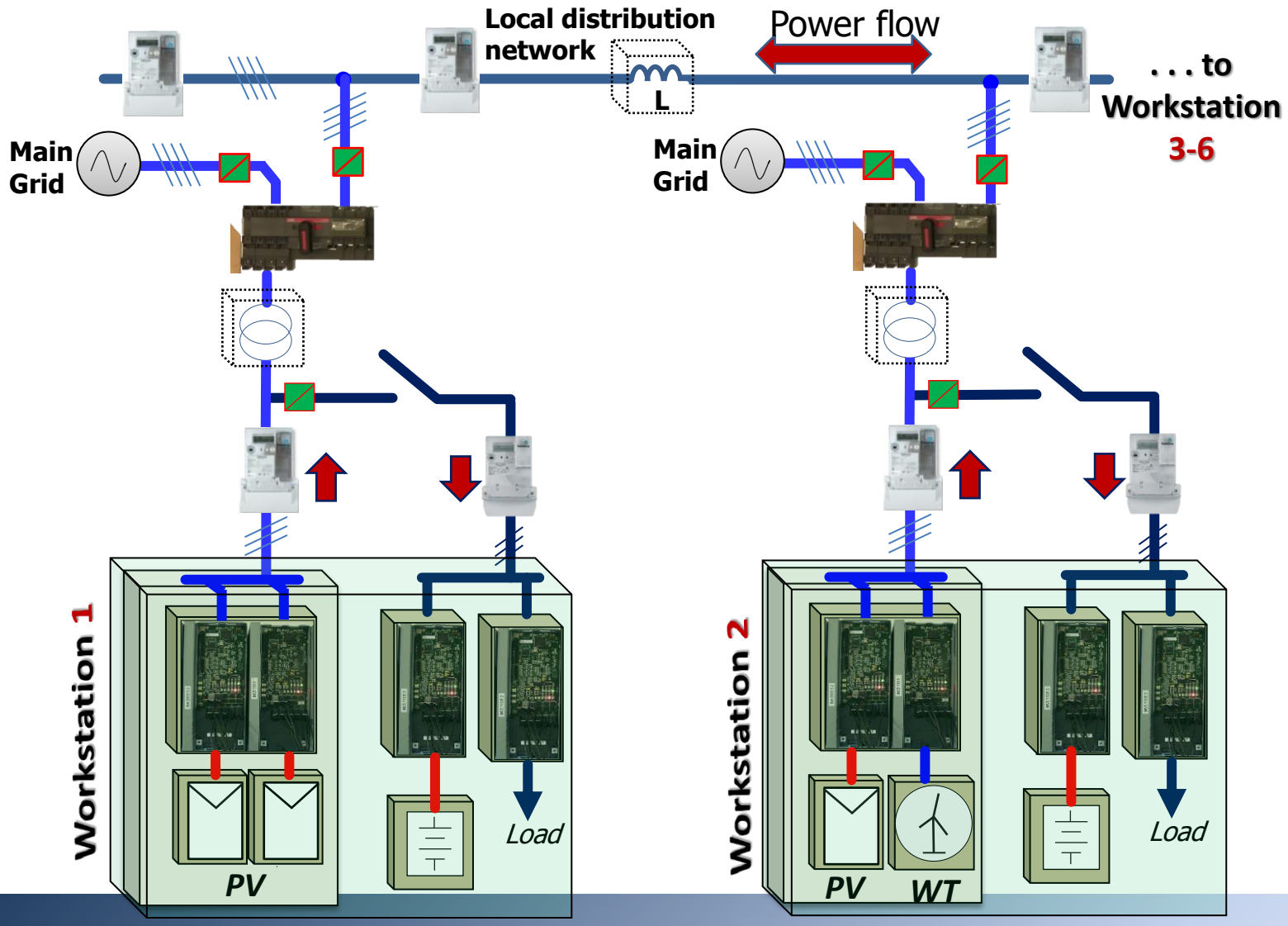
Control schemes from Matlab/Simulink library are directly compiled into C code and downloaded to the dSPACE



# Microgrid Central Controller – EMS in labview



# Power hardware in the loop microgrid system



# Smart Metering in Smart Microgrids – A Danish Scenario

MULTICAL®
Smart Meters for water

MULTICAL®
Smart meters for district heating

OMNISOFT
VisionAir software for data management and storage

OMNICON
UtiliKeeper® or costeffective substation monitoring

OMNICON
Data concentrator for communication infrastructure management

OMNICON
Wireless communication to in-house displays

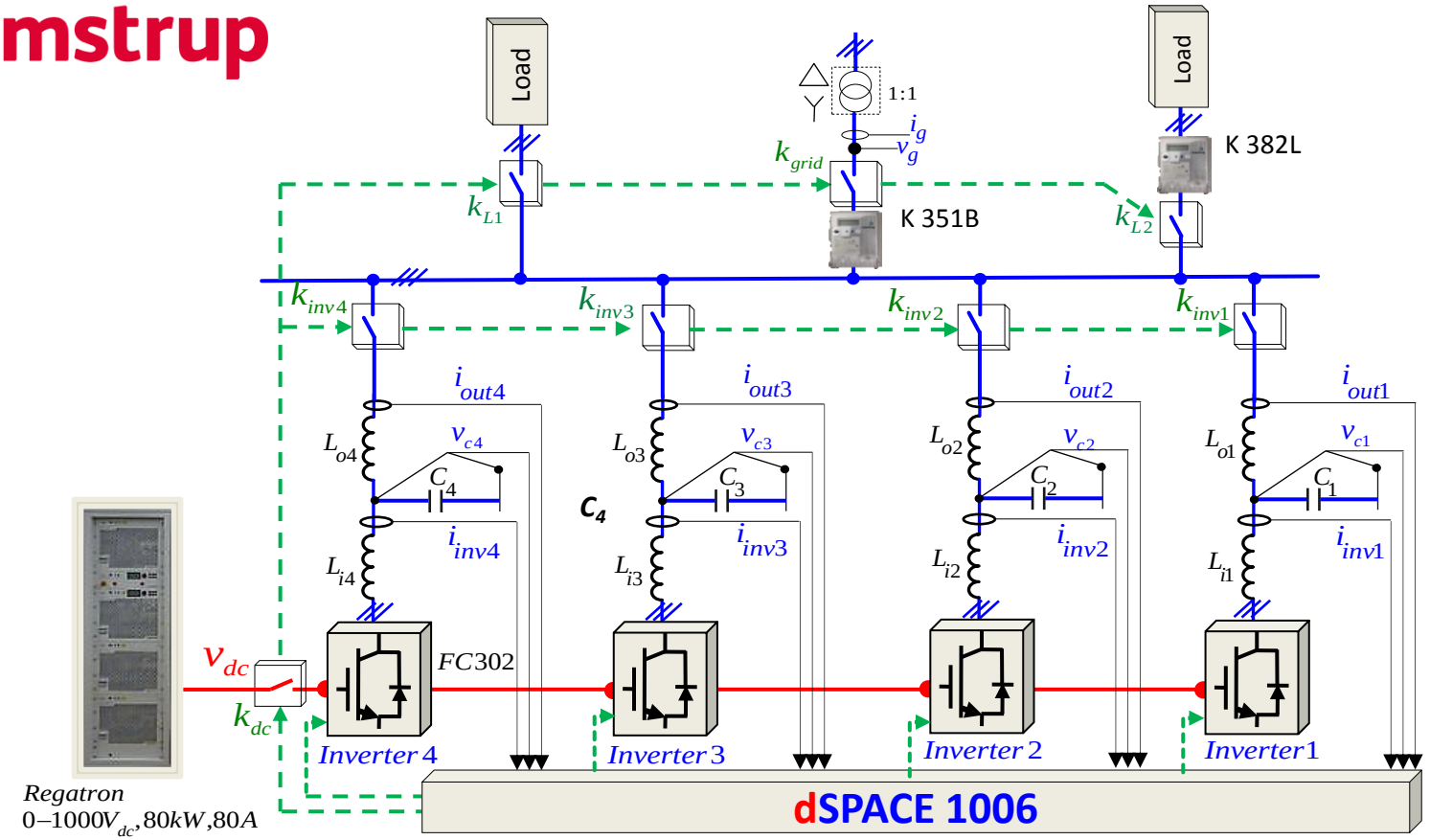



**OMNIA Smart Metering System**

# System Overview – Microgrid Research Lab

- **Kamstrup 351B**: Industrial Smart Meter. Measures the total generating power (DG)
- **Kamstrup 382L**: Residential Smart Meter. Measures load consumtion (Home/Building)

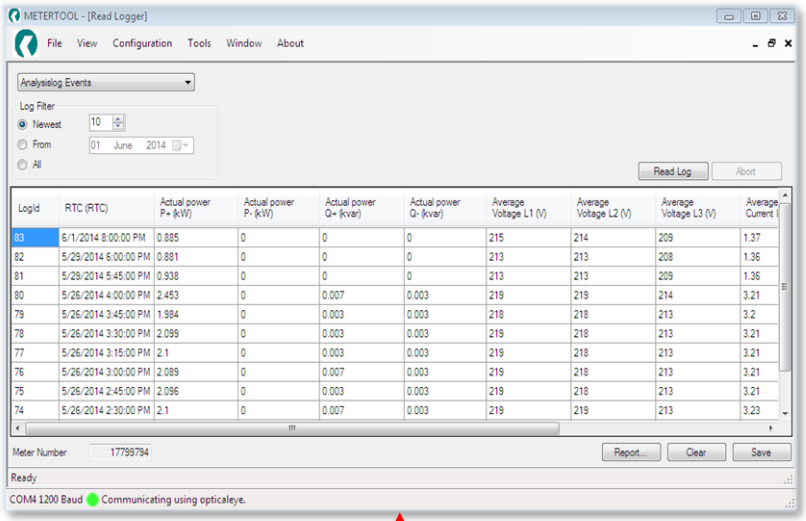
kamstrup



# System Overview

## Communication with Smart Meters

METERTOOL Kamstrup Software


**DLMS/COSEM over TCP/IP**

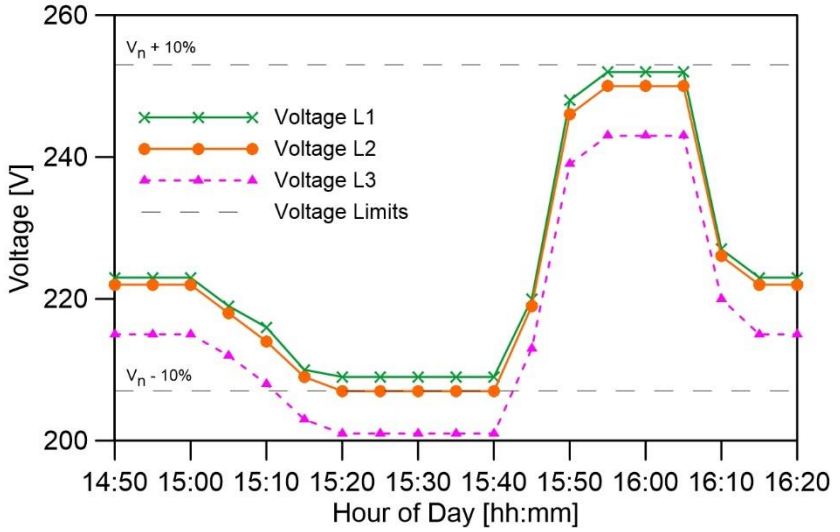
DLMS/COSEM over
Serial Optical Port

IEC 62056-21
over Optical Port

# Example: Voltage Quality Events Detection

- Three-phase voltages
- 5 minutes resolution

- ±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 |

# EUDP Sino-Danish project

MicroGrids RESEARCH PROGRAMME


## Microgrid Technology Research and Demonstration 2014 - 2017

AALBORG UNIVERSITY DENMARK

Kamstrup

上海太阳能科技有限公司 ShangHai Solar Energy Science & Technology Co.,Ltd.

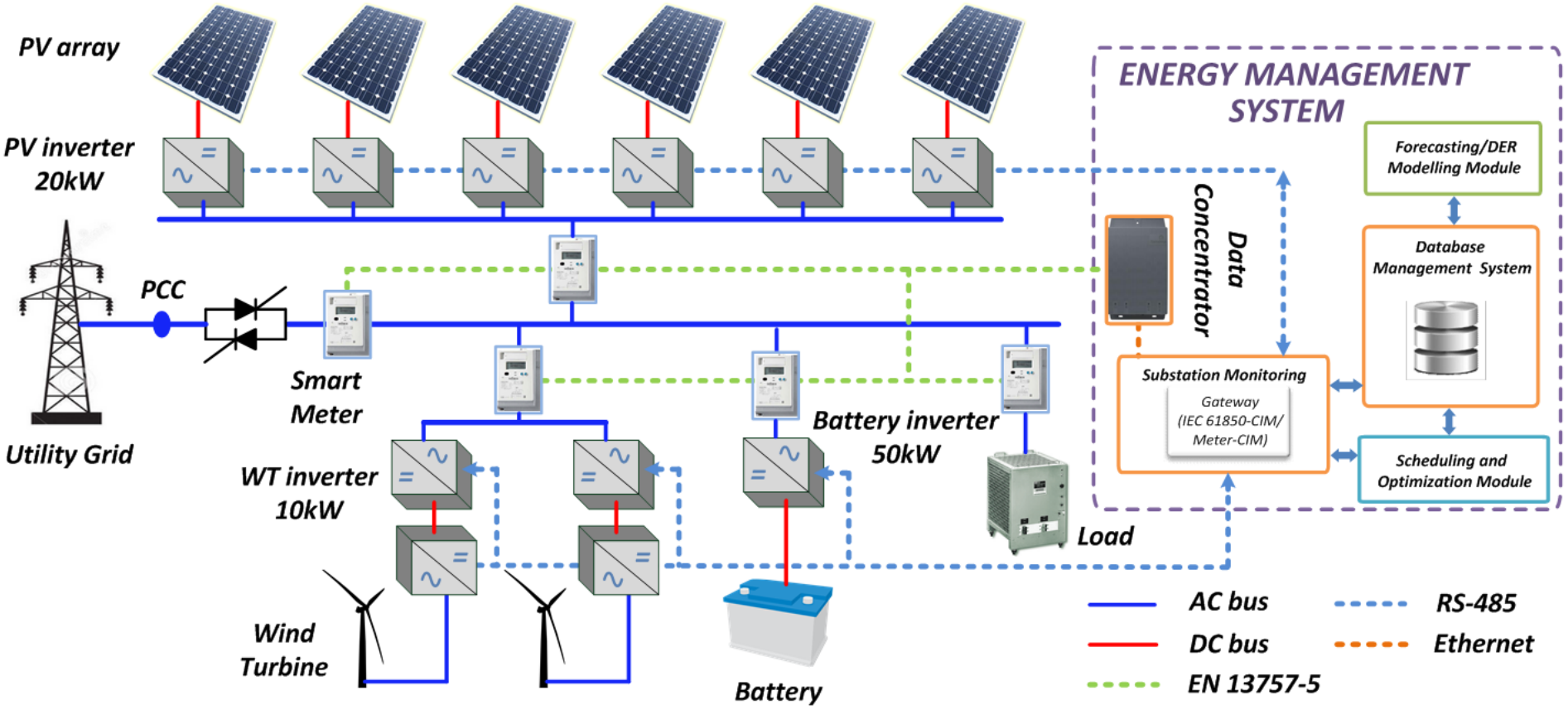
清華大學 Tsinghua University

EUDP Energiteknologisk udvikling og demonstration

中华人民共和国科学技术部 Ministry of Science and Technology of the People´s Republic of China

Microgrid Research programme: www.microgrids.et.aau.dk

# 200kW Microgrid based on wind/PV/storage hybrid system



# 200kW Microgrid based on wind/PV/storage hybrid system

## *PV power generation subsystem*

PV array installed on the roof of **Shanghai ShenZhou** New Energy B plant, installed capacity of ***130 kVA***, east-west array configuration, adopt the fixed angle best installation.

# 200kW Microgrid based on wind/PV/storage hybrid system

## Wind power generation subsystem

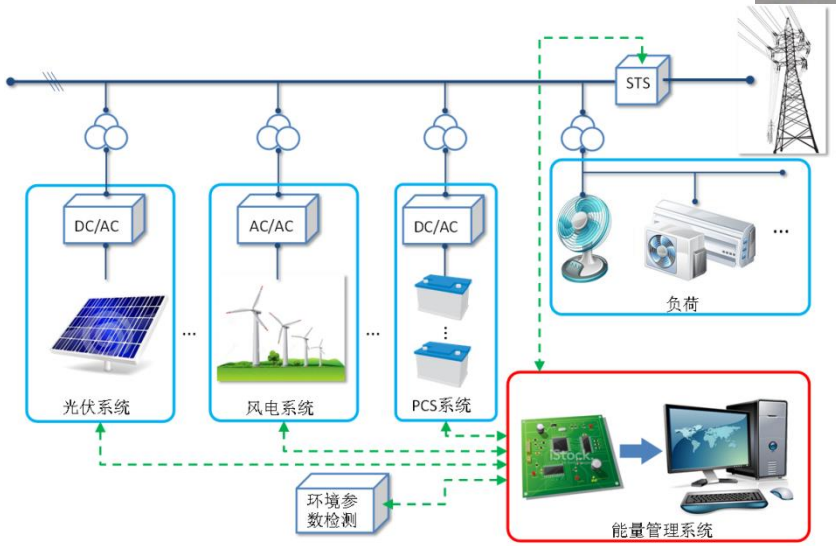
***Total wind power installed capacity**: 20kVA. (2 x 10 kW Wind Turbines)*

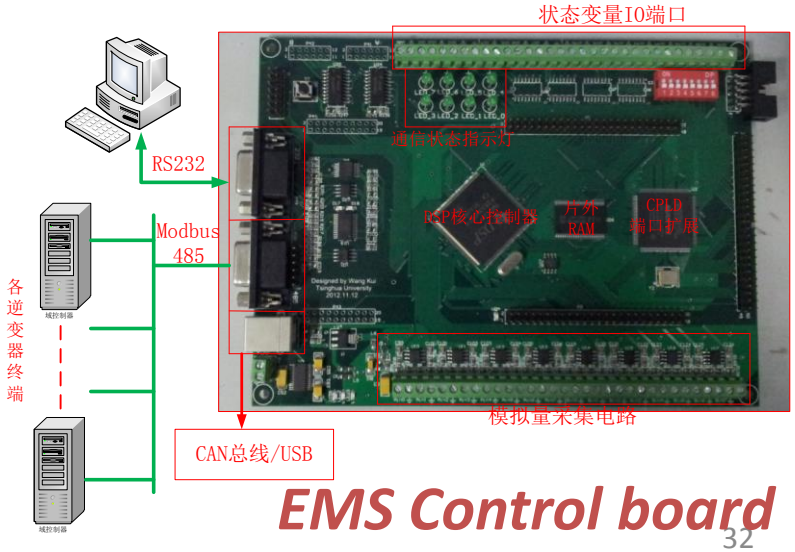
# 200kW Microgrid based on wind/PV/storage hybrid system

**Energy Storage System**

**50kVA Bi-Directional Converter + Lead-Acid battery**

**Energy Management System**




**EMS Control board**

# Hierarchical Control Strategies

Demand Response
Scheduling, EMS

Power Export/Import

ω / V Restoration
Grid Synchronization

Current, Voltage inner loops
Droop Control

Tertiary Control

Secondary Control

Primary Control

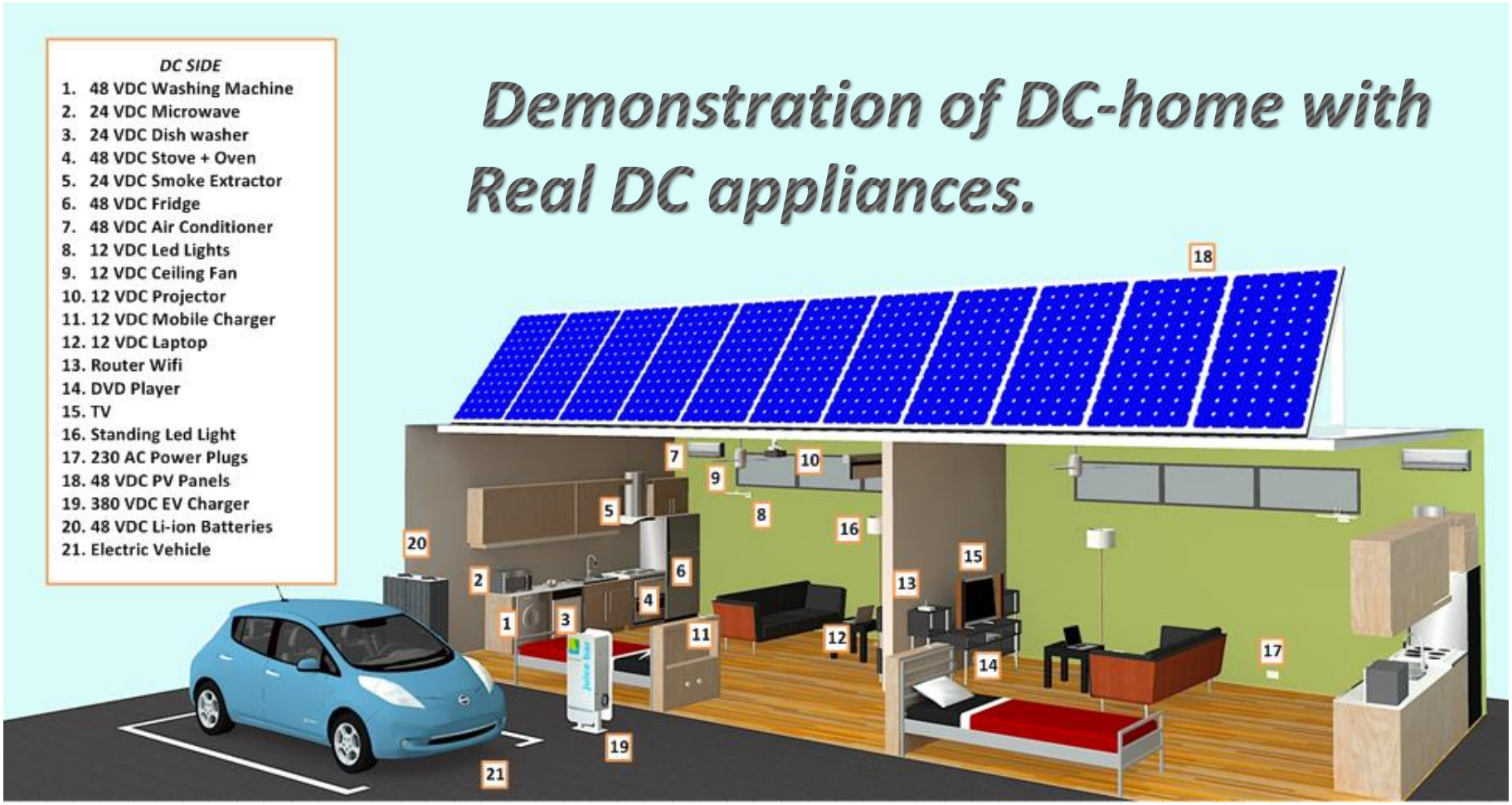
days
hours
minutes
seconds
ms
µs

Time Period →

***Main goal***

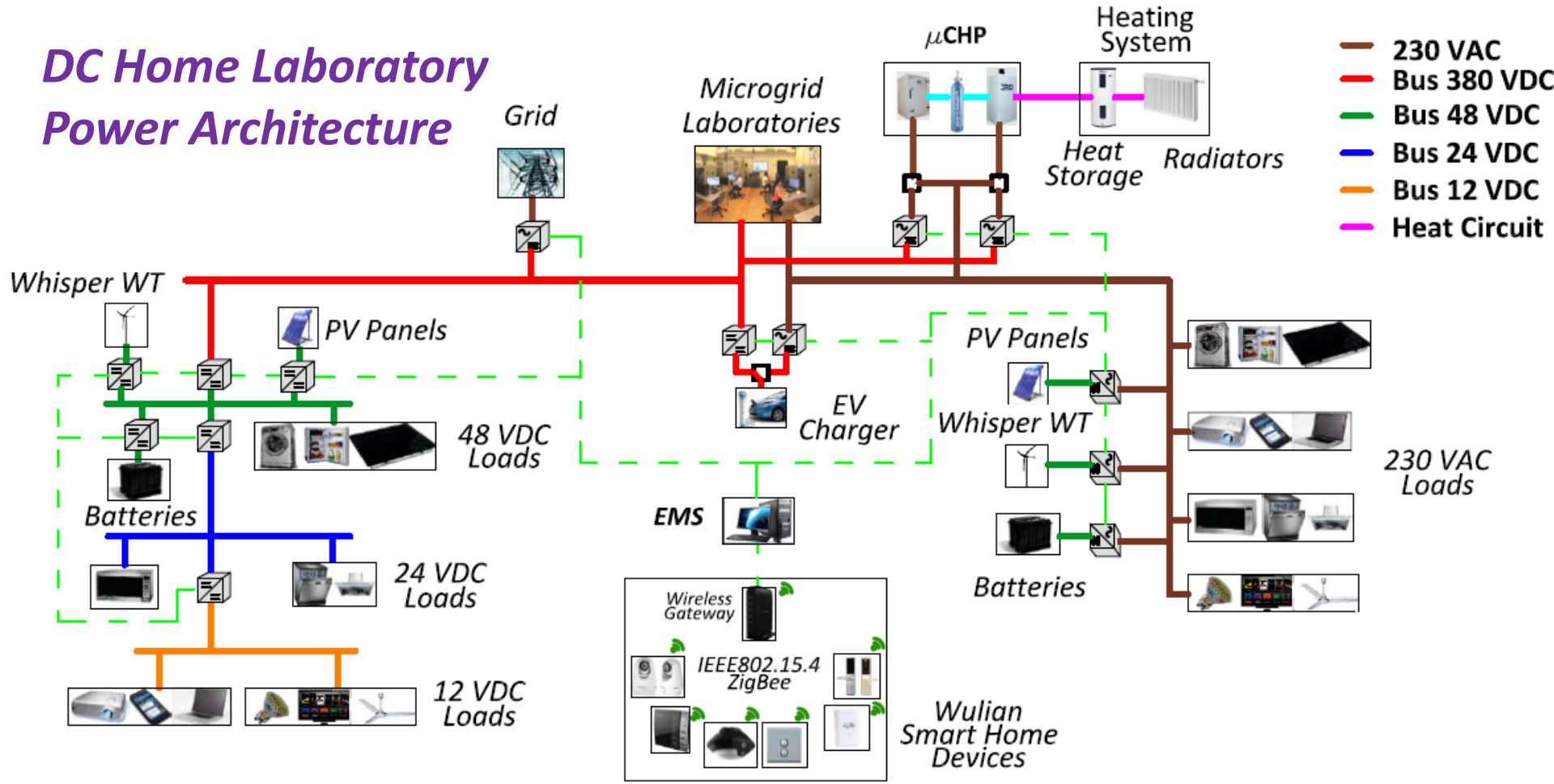
**Integration of Smart Meters in the Control Hierarchy**

# Intelligent DC Microgrid Living Lab



# Intelligent DC Microgrid Living Lab

## DC Home Laboratory Power Architecture



MicroGrid Research Programme

# DFF project 2014-2016

# Future Residential LVDC Power Distribution Architectures

*International ranked research institutions*

INESCTEC TECHNOLOGY & SCIENCE ASSOCIATE LABORATORY

立命館大学

VirginiaTech

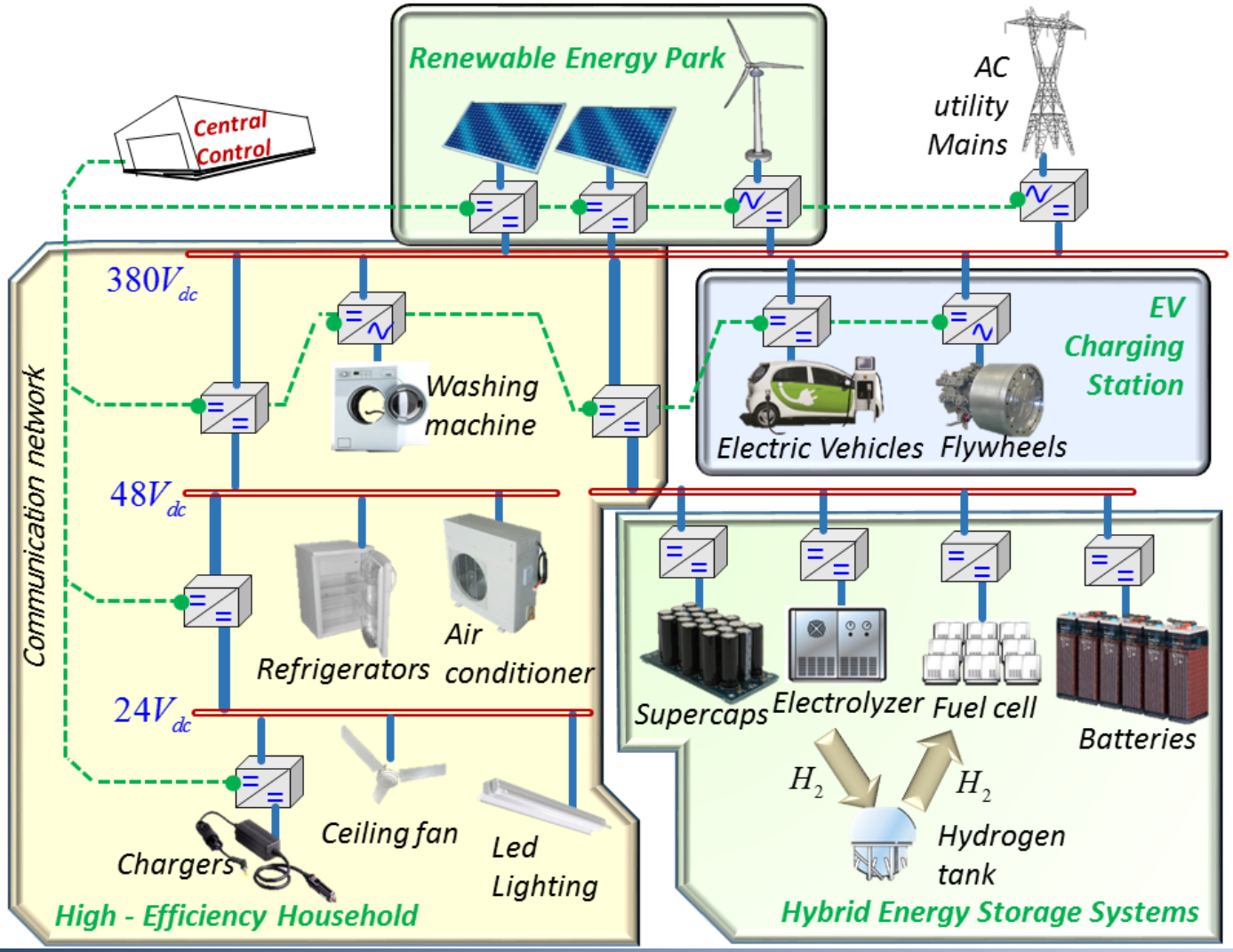
*And the Danish Companies*

kk-electronic a/s

Kamstrup - metering solutions

NEOGRID TECHNOLOGIES

# Future Residential LVDC Power Distribution Architectures



# Future Residential LVDC Power Distribution Architectures

*Lighting & air fan*

*TV set*

*Refrigerator*

*Washing machine*

*Electric oven*

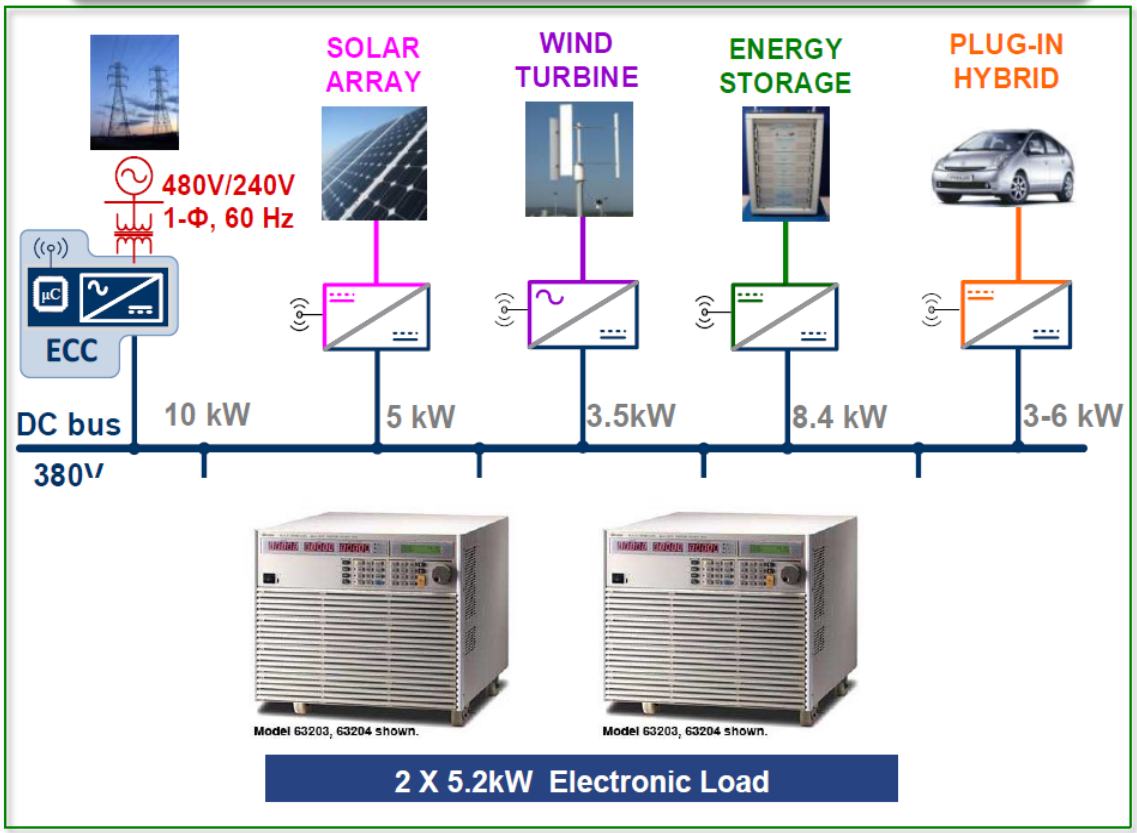
**All of the electric appliances work by 380 VDC!**

***380 VDC socket-outlets provided by NTT-F***

# CPES: *Hybrid AC-DC NanoGrid System*

## Minimized System for Validation

**Minimized REN system (ECC, PV, Bat, Load)**

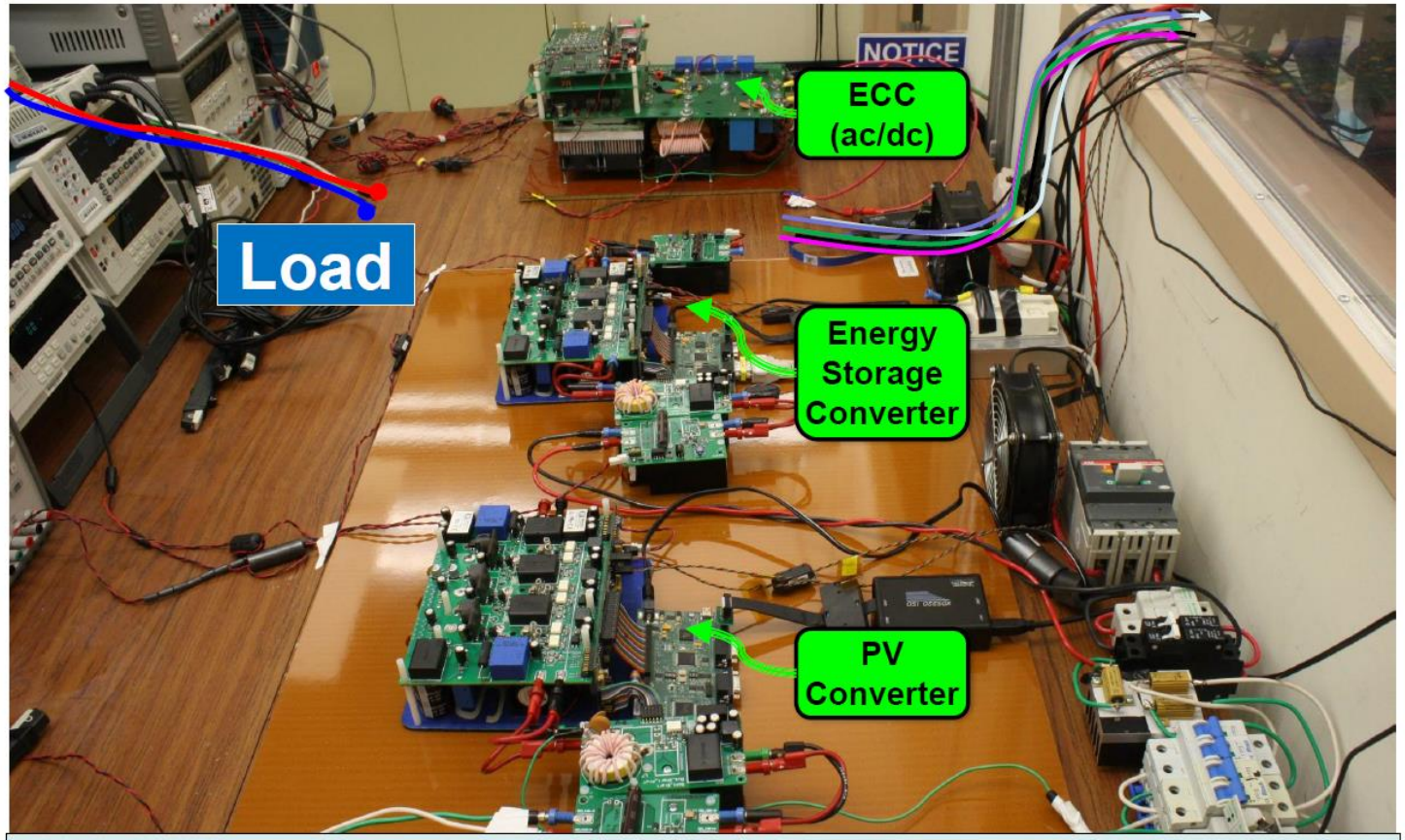



- **Generation**
  - Solar, Wind;
  - FC, Generator;
  - • • •
- **Energy storage**
  - Batteries;
  - CA, Flywheel;
  - • • •

**4. Load demand**

# CPES: *Hybrid AC-DC NanoGrid System*

## Testbed for Future Home




Load demand and PV source profile could be remotely programmed

MicroGrid Research Programme

# ERANET project 2014-2016

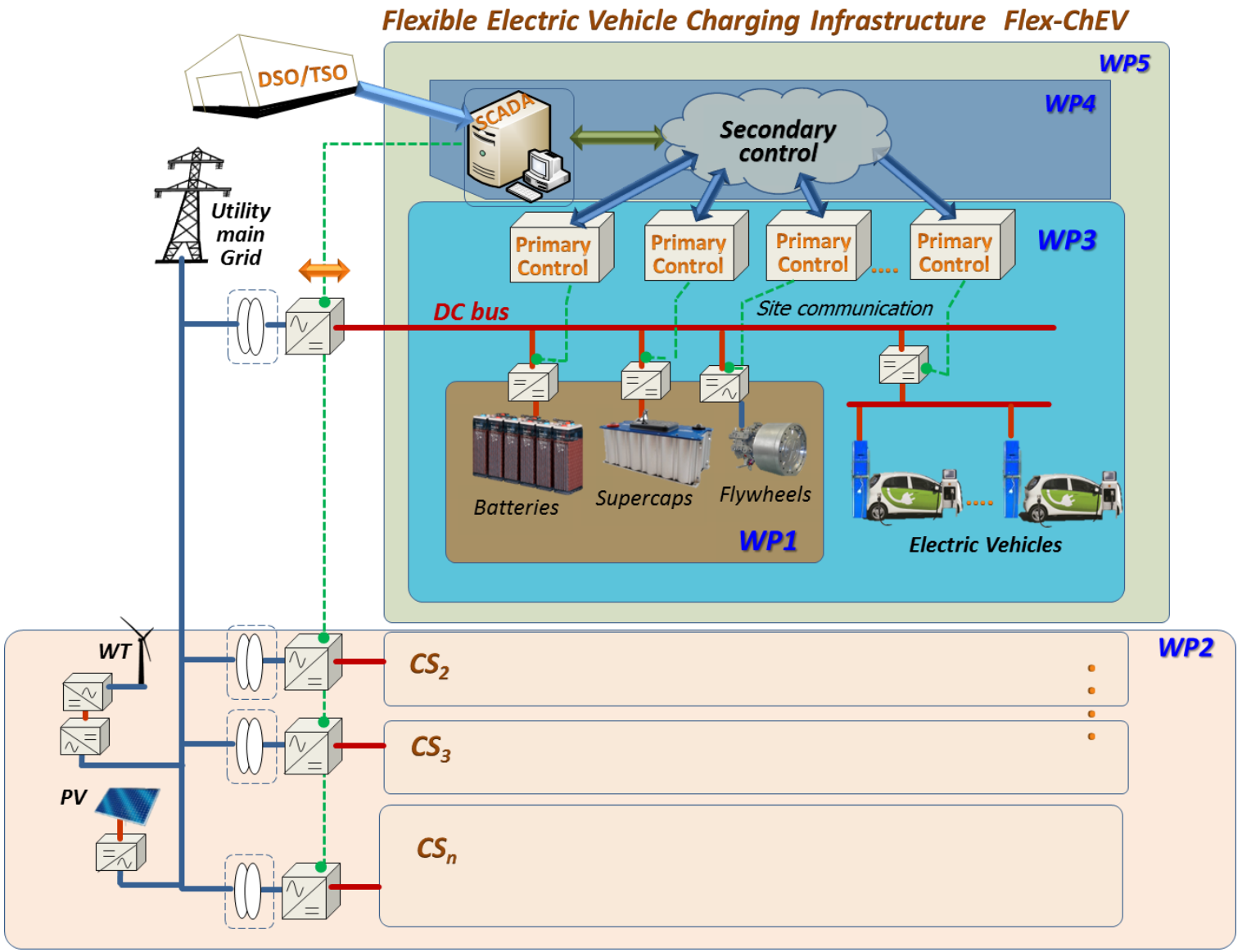
# Flexible electric vehicle charging infrastructure Flex –ChEV

AALBORG UNIVERSITY
DENMARK

HØGSKOLEN I NARVIK

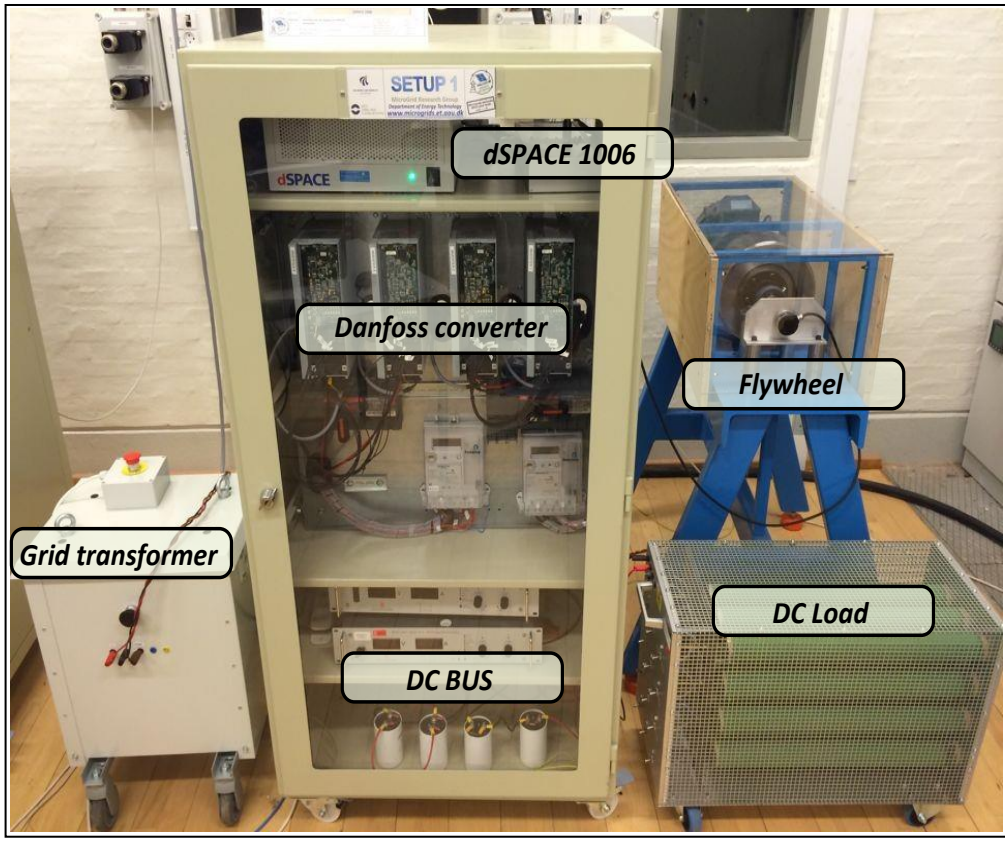
UNIVERSITAS STUDIORUM ZAGRABIENSIS MDCLXIX

# Flexible electric vehicle charging infrastructure Flex –ChEV



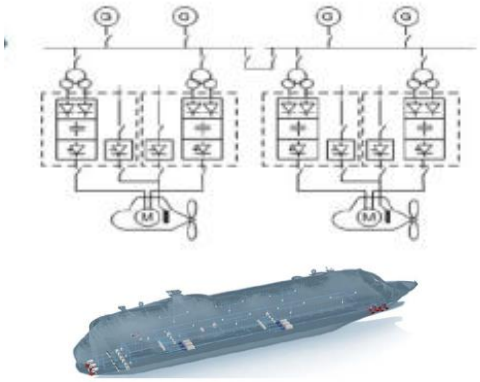
# Flexible electric vehicle charging infrastructure Flex –ChEV

- Control design of IM based flywheel for grid ancillary services
- 2.2 kW expiremental test-bed has been built
- Fully modular control strategy based on distributed bus signalling -> scalable to units of different size

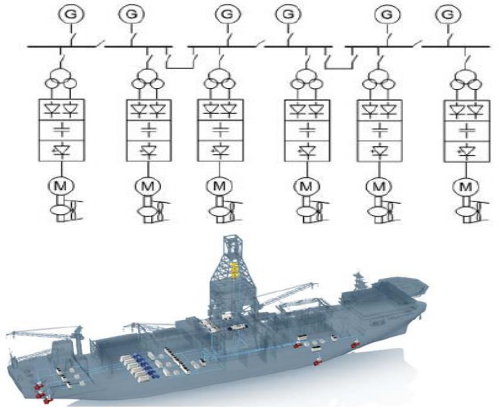


# State-of-the-art of SPS

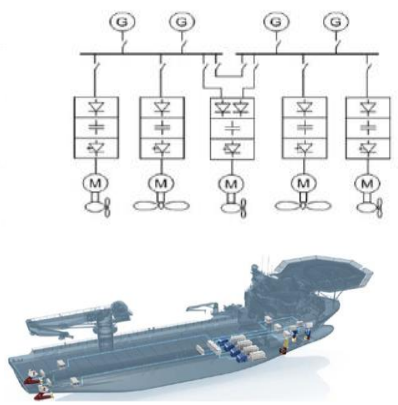
- The electric propulsion solutions applied for some of the main vessel types.
- Based on the difference requirement of the ship mission.



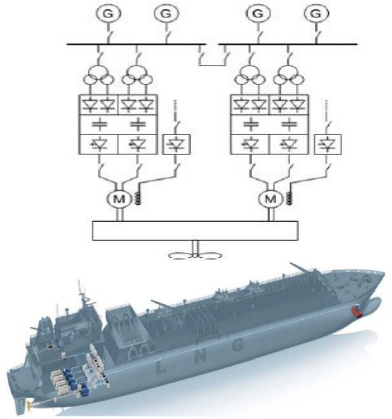
Cruise vessel with power and propulsion overview.



Drillship with power and propulsion overview.



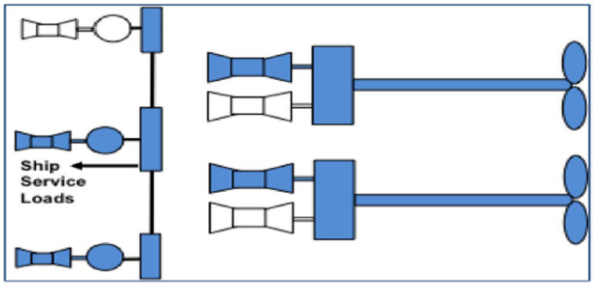
Offshore support/construction vessels with power and propulsion overview.



LNG Carrier with power & propulsion overview.

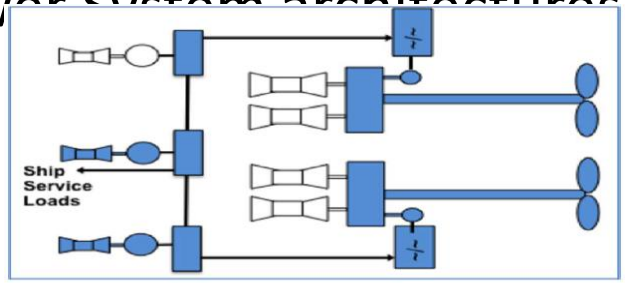
# State-of-the-art of SPS

## Shipboard Power System architectures



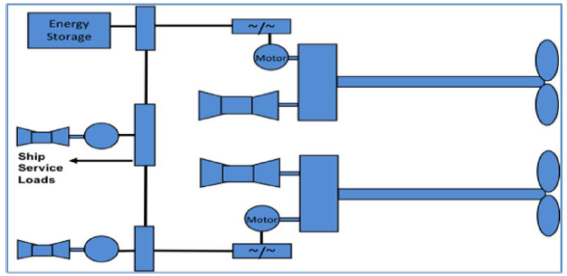

**Segregate electric plant architecture**.

The propulsion and power generation separated.




**Hybrid electric propulsion system architecture**.

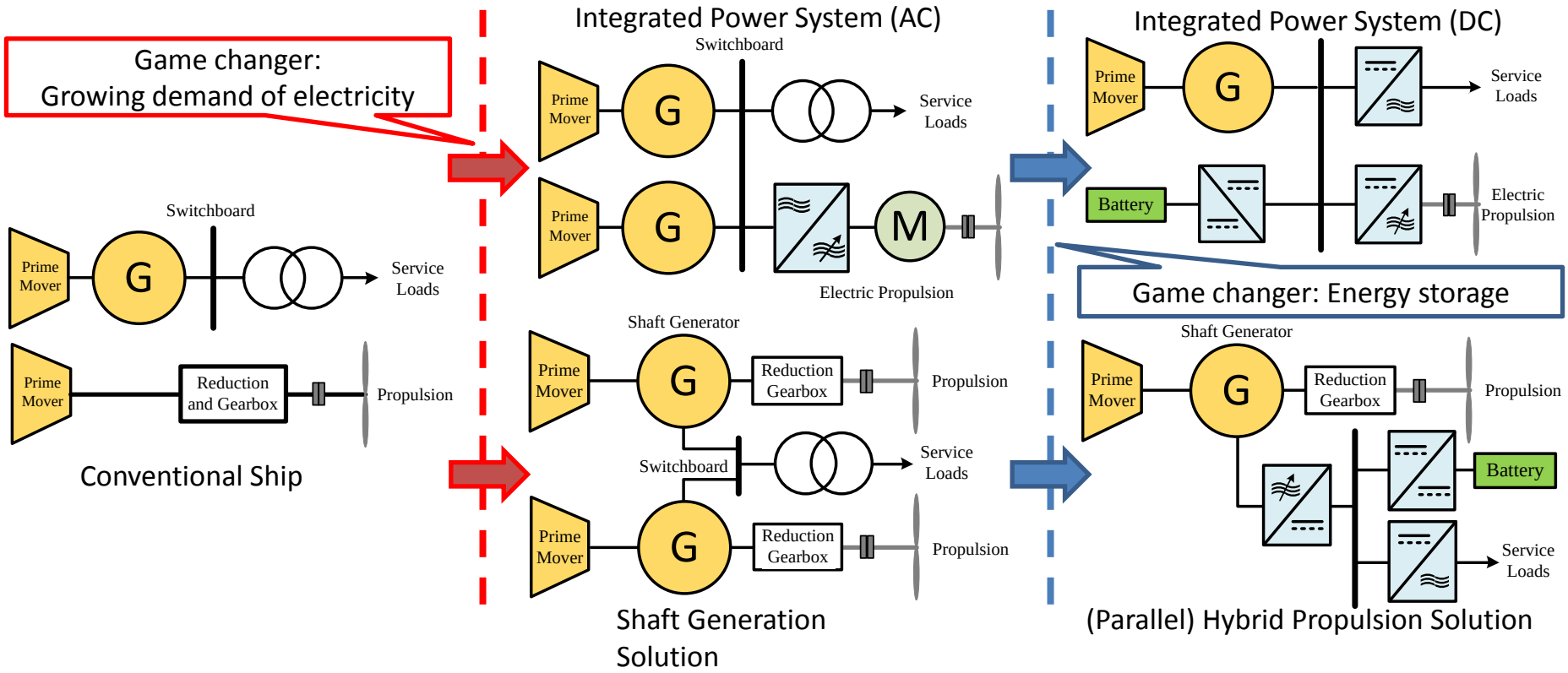
Propulsion is provided at low speed by electric motor. At higher speed provided by the prime movers propulsion power.




**Hybrid electric propulsion system with energy storage architecture**.

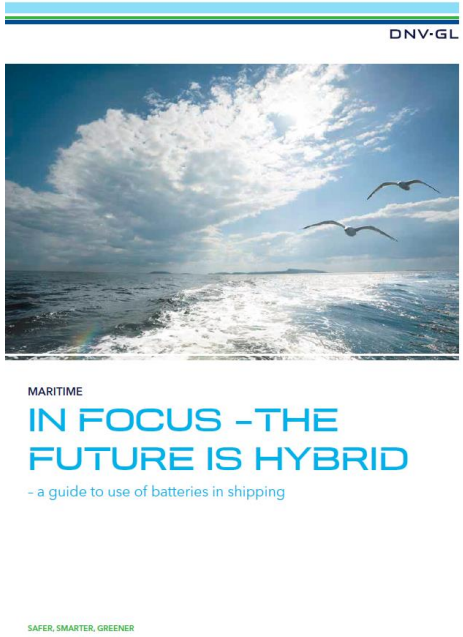
The energy storage allows for more optimal operation of the prime movers for reduced emissions and fuel consumption

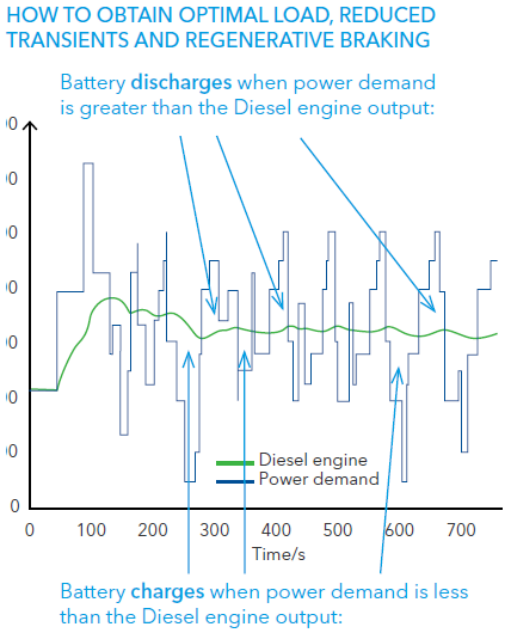
# State-of-the-art of SPS

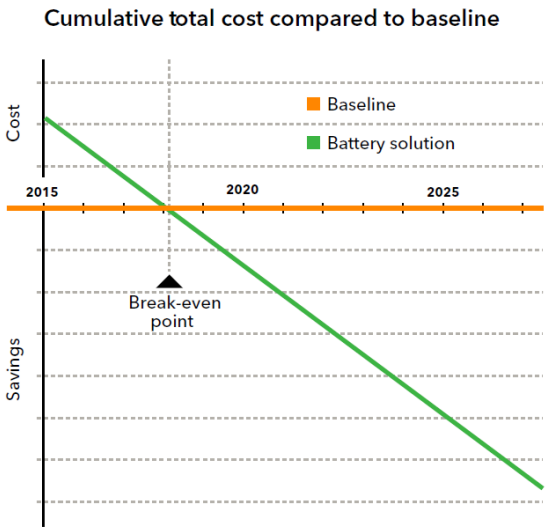


# State-of-the-art of SPS

Listen to the industry and look at the trend (DNV-GL: IN FOCUS- The future is hybrid) :



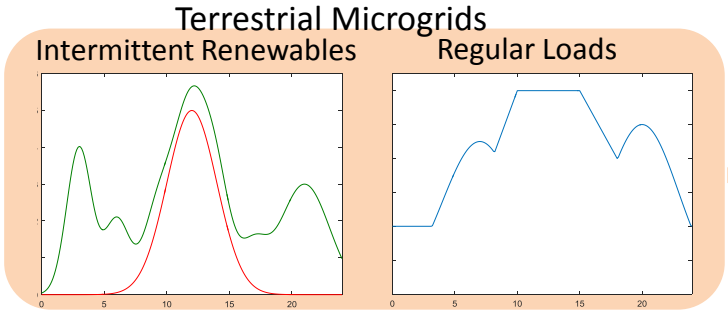




Investment costs and operational costs in a life cycle perspective. The analysis illustrates payback time and the value of the investment over the lifetime of the ship for relevant options.

# State-of-the-art of SPS

## Terrestrial Microgrids V.S. Shipboard Microgrids:

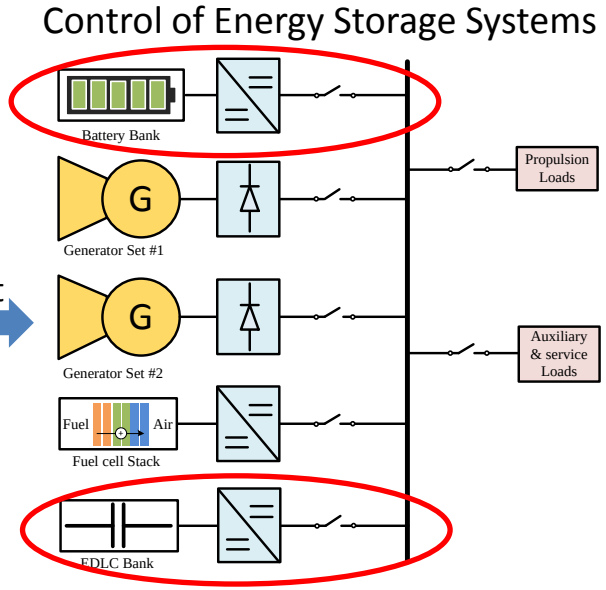



Intermittency Compensation

Mismatch in Generation & Consumption

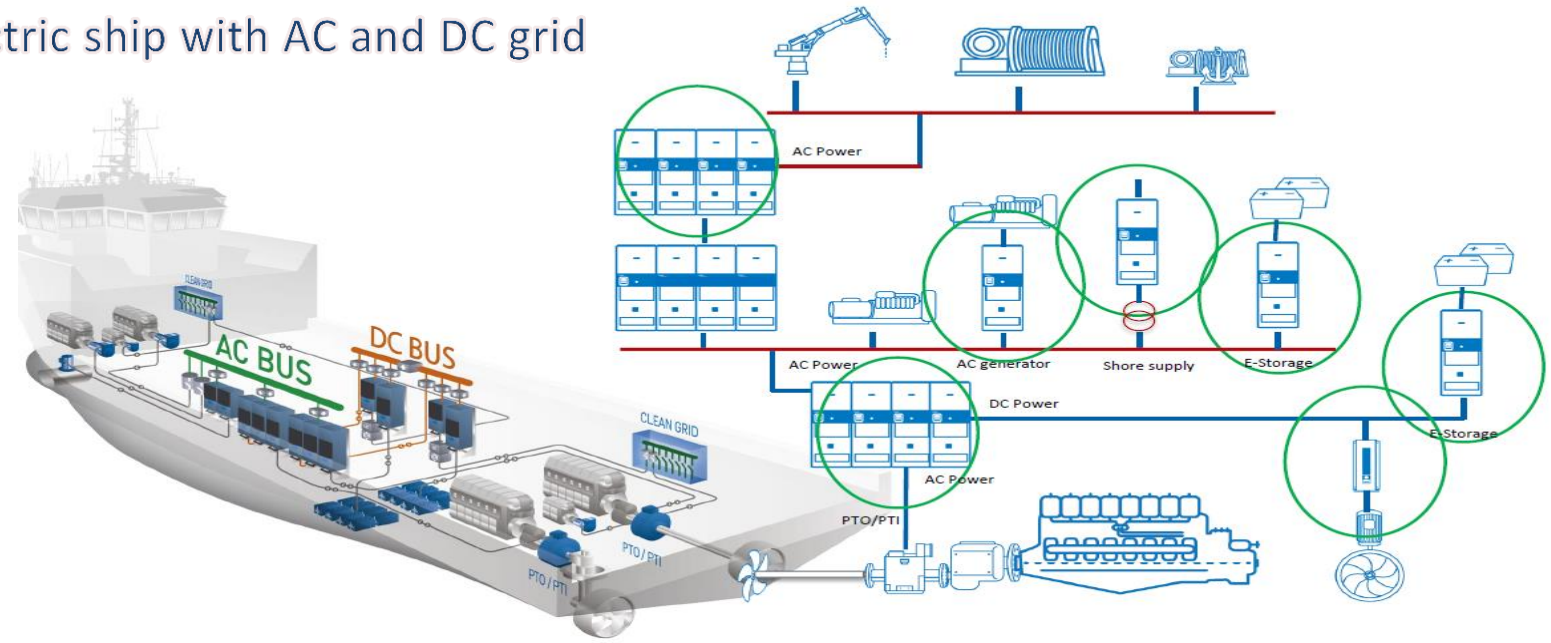
Instant Power Support

Key Point



# State-of-the-art of SPS

Fully electric ship with AC and DC grid



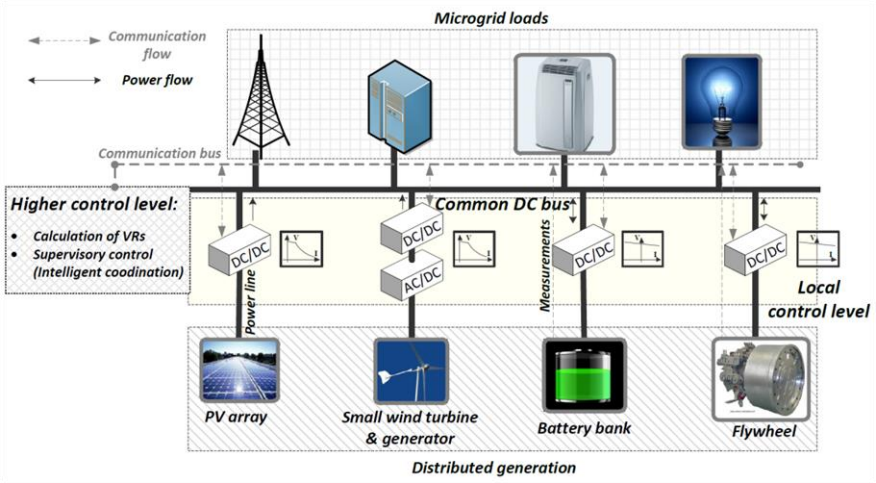

Source: Vacon Power / Danfoss

# A Comparative Study of MG and SPS

## Terrestrial Microgrids:

A terrestrial MG can be defined as a cluster of local renewable energy sources, energy storage systems and various critical or non-critical electrical loads bound with local power distribution network, which may be isolated (standalone) or connected (grid-tied) with the utility grid and/or other microgrids as a single entity.

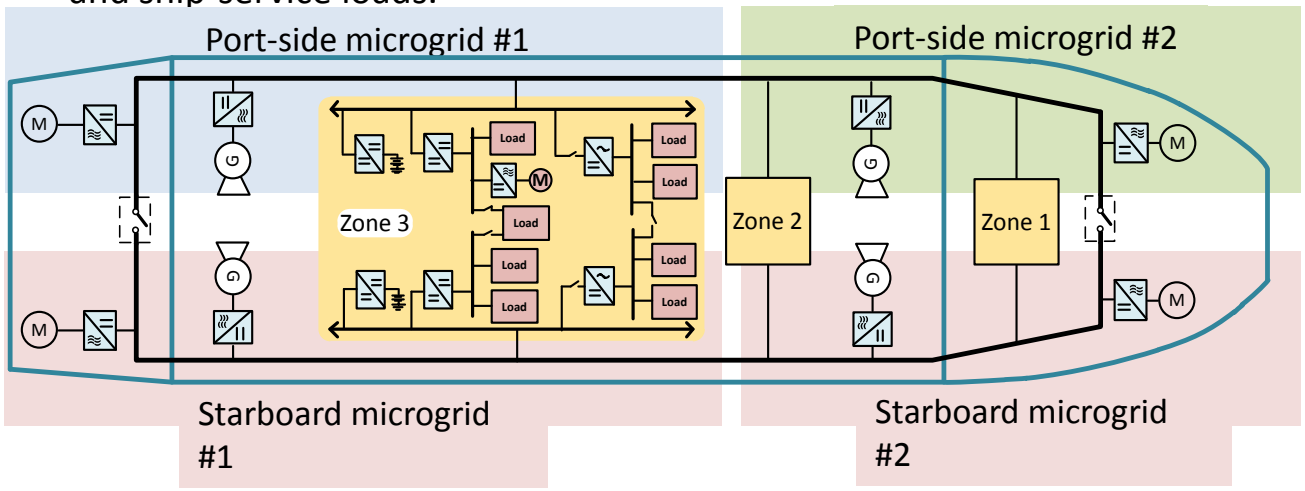
The concept itself may have a great chance to become the foundation of future terrestrial distribution system due to its inherent convenience to integrate several different means of generation and higher efficiency.

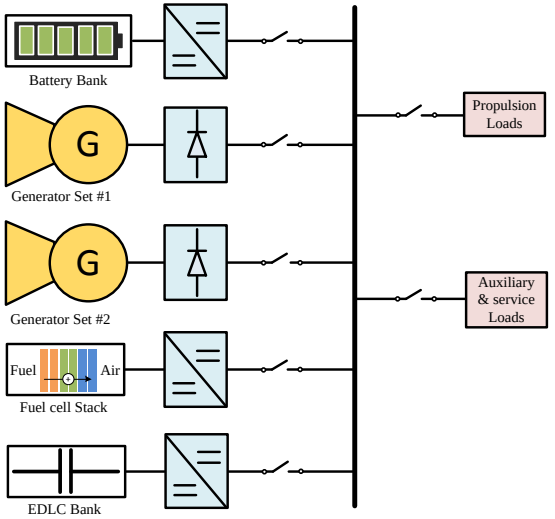


# A Comparative Study of MG and SPS

## Defining Shipboard Microgrids:

Recommended by IEEE STD 1709-2010 [8], a DC shipboard MG is composed by gensets, centralized or hybridized ESSs, alternative power sources (APSs) [e.g. fuel cell and PV array], electric propulsion system and ship-service loads.




Single-Line Diagram of a sectionalized microgrid

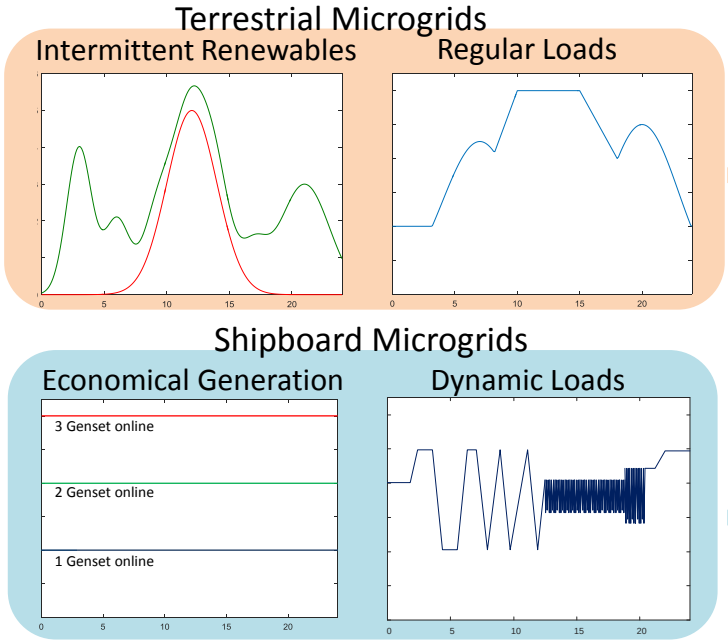
# A Comparative Study of MG and SPS

Terrestrial Microgrids V.S. Shipboard Microgrids:

| Application | Terrestrial Microgrids | Shipboard Microgrids |
|---|---|---|
| Generation | Mainly Renewables (Intermittent Source) | Mainly Diesel Gensets |
| Storage | Battery, EDLC and Flywheel | Mainly battery; EDLC as option. |
| Loads | Stable or regularly changed loads | Dynamic non-linear propulsion loads |
| Control | Three-layer hierarchical control. | Excitation control and inherent droop effect. |
| Optimization | Real-time and offline methods | Pre-designed curves. |

# A Comparative Study of MG and SPS

## Terrestrial Microgrids V.S. Shipboard Microgrids:

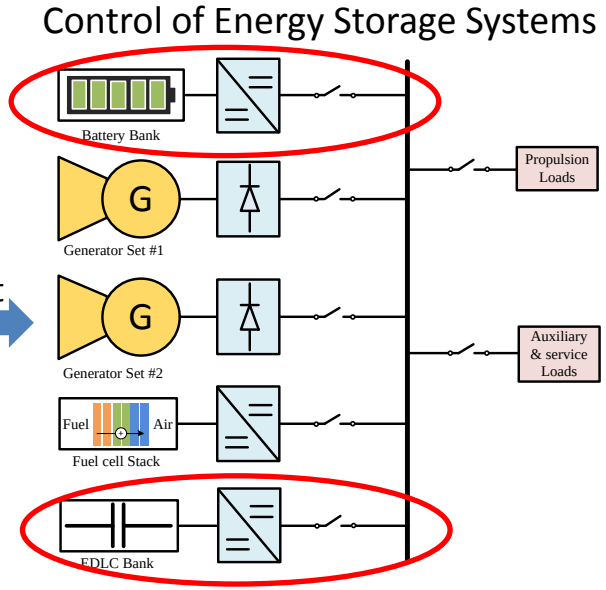



Intermittency Compensation

Mismatch in Generation & Consumption

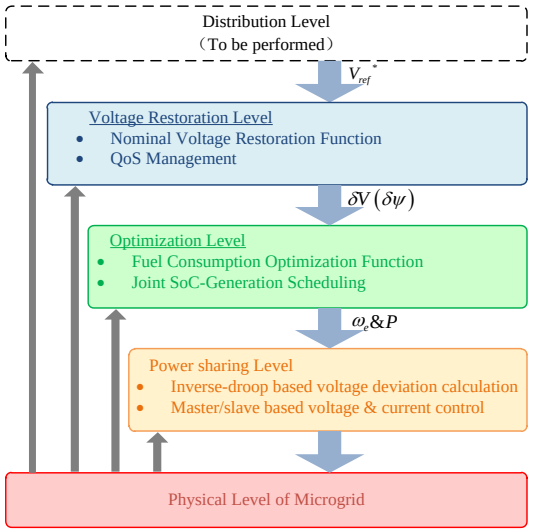
Instant Power Support

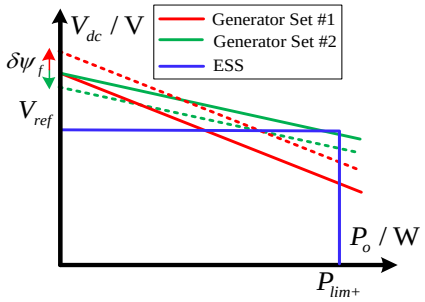
Key Point

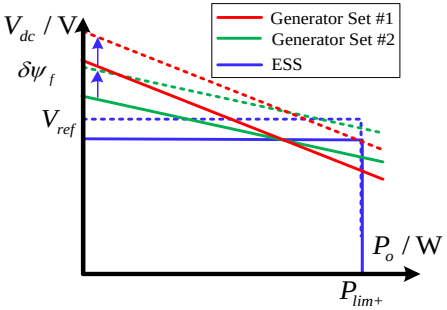


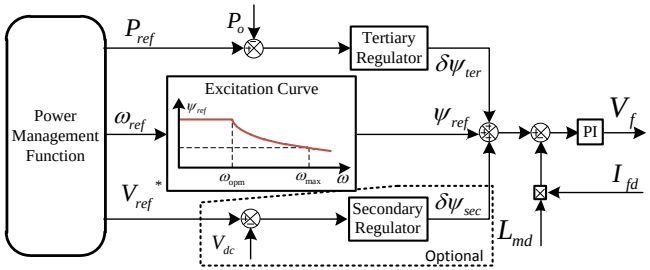
# State-of-the-art of SPS

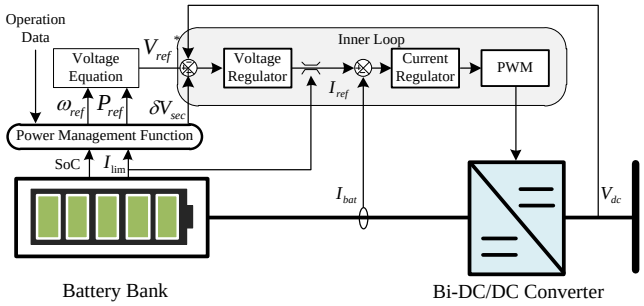
## Higher levels design:



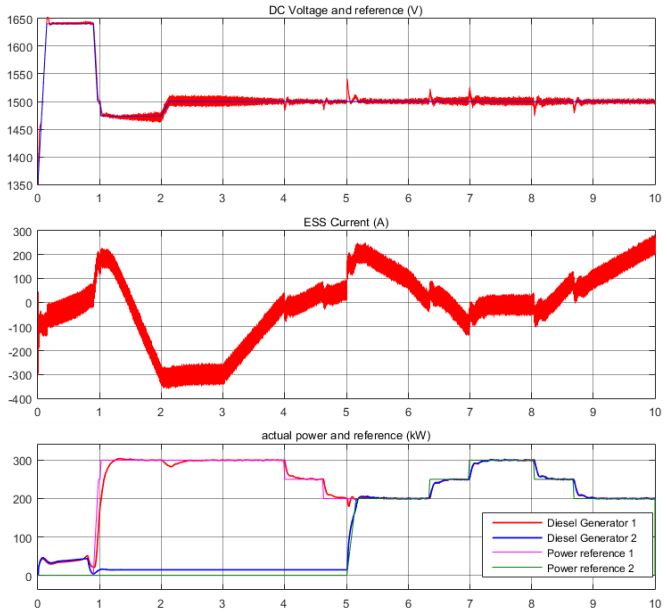



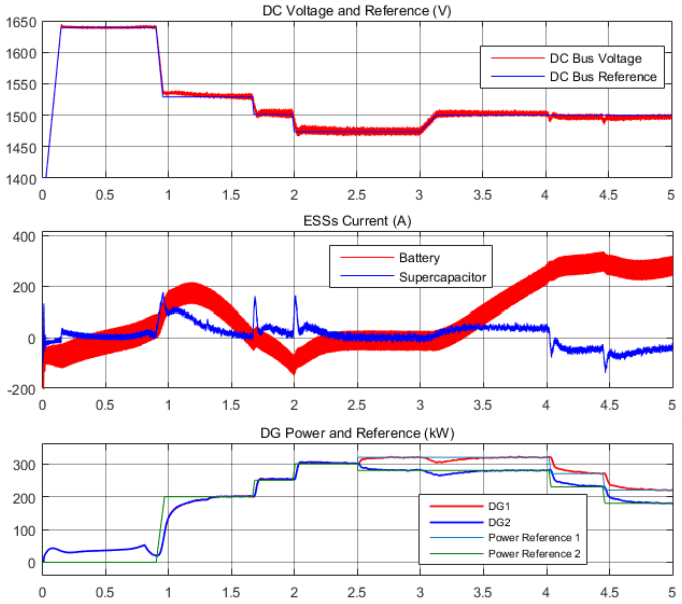
# State-of-the-art of SPS

## Real-time Simulation Results:

### Using Inverse-droop




### Using Frequency-division Inverse-droop



# Poland – Denmark Cooperation PhD Project 2017

# Unbalance and Harmonic Analysis in Shipboard Microgrids

AALBORG UNIVERSITY
DENMARK

GDYNIA MARITIME UNIVERSITY
1920
POLAND

# PQ Standards in SPS

TABLE I. CLASSIFICATION OF SOCIETY RULES AND STANDARDS

| *Standards* | *Instrument and parameters Variations* | | |
|---|---|---|---|
| | *Voltage transient* | *Frequency transient* | *THD* |
| ABS (2016)<br>DNV (2016)<br>IEEE Std.1662-2016 (2016)<br>IEC Std.61557-12 (2007)<br>PRS(2016) | $\pm 20\%, 1.5s$ | $\pm 10\%, 5s$ | $8\%(50th)$ |
| STANAG1008 (Ed8, Ed.9)* | $\pm 16\%, 2s$ | $\pm 4\%, 2s$ | $5\%(40th)$ |
| * for the naval ship | | | |

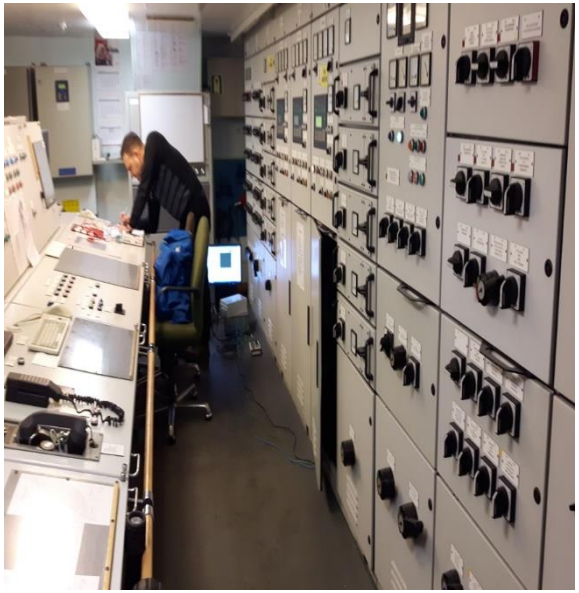
(2)

However, few maritime standards clarified the detailed requirement for the power system onboard except PRS, it is requires that the grid voltage unbalance factor should not be higher than 3% for any electric power system in ships. For the naval ship, only lower than 2% unbalances are permitted for the continuous grid voltage conditions.

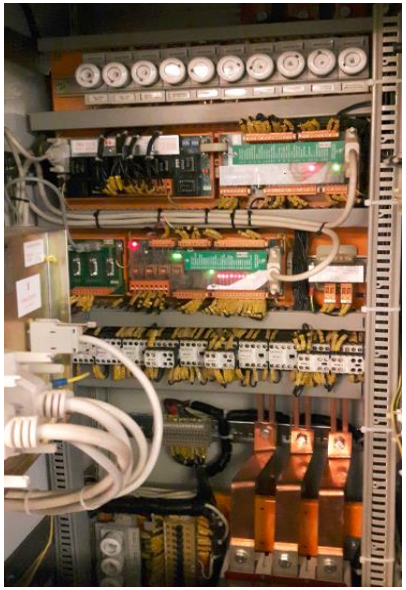
# Horizon II

Ship

Engine room



Control board



Diesel generator

Pump

# Horizon II

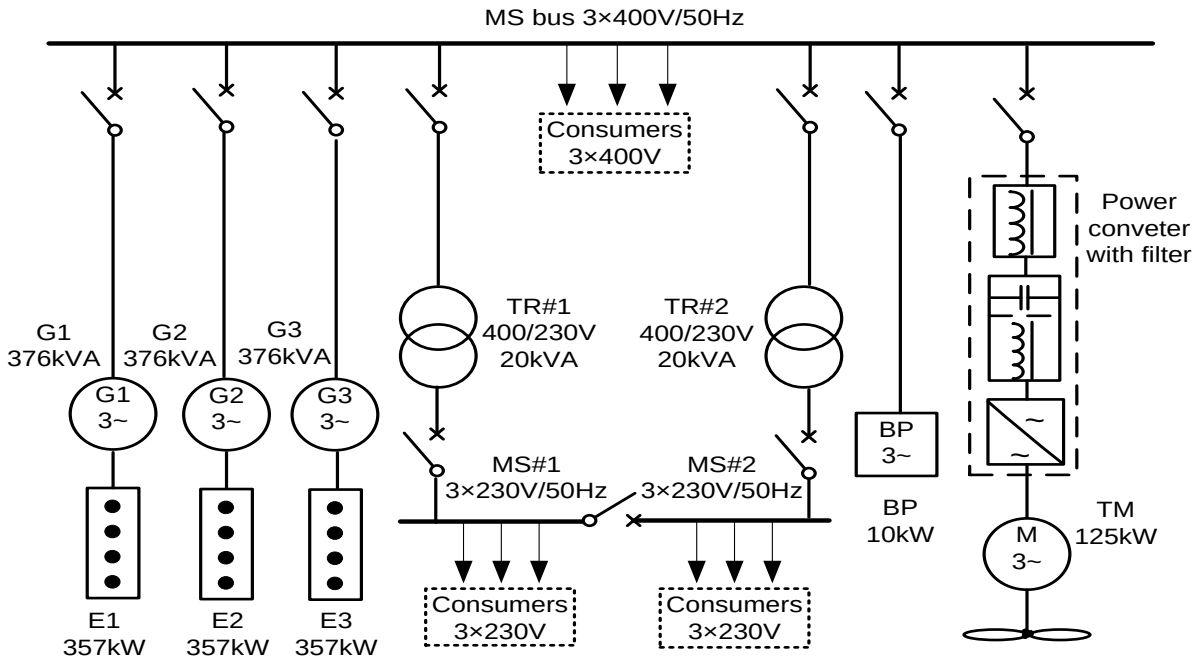
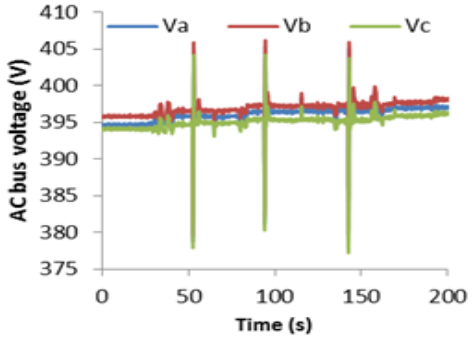


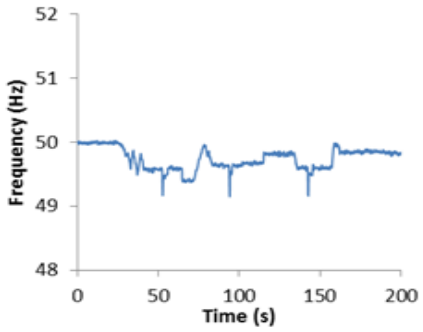

Fig .1 The industrial AC MMGs based on Horizon II ship

(2)

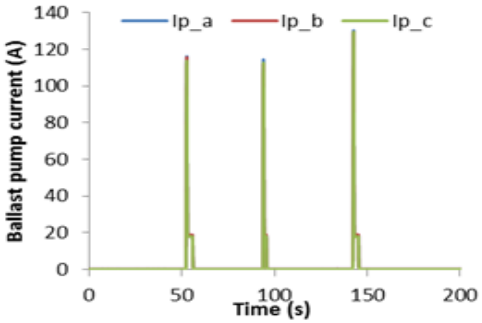
# Case A
# SPS working under normal grid conditions



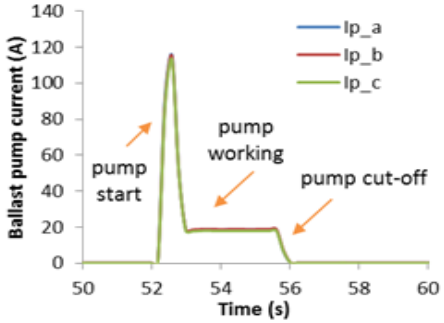

(a) AC bus voltage



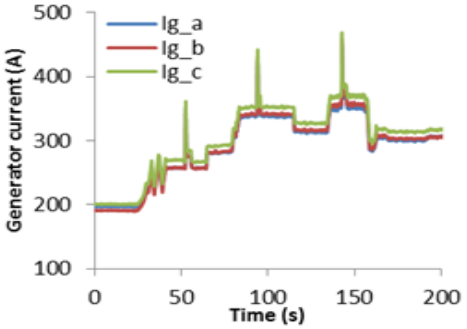

(b) grid frequency



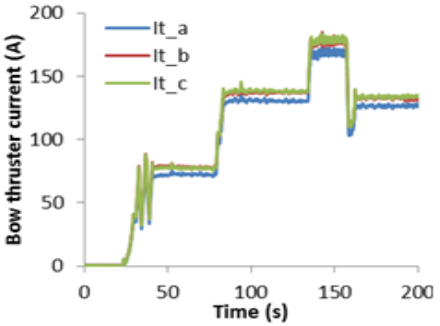

(c) pump current



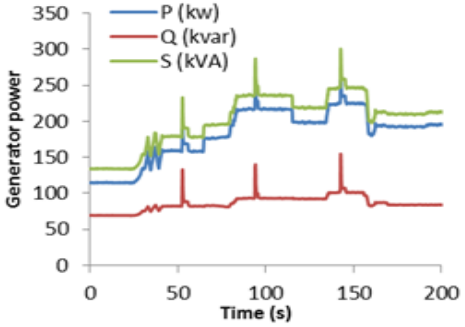

(d) pump behavior



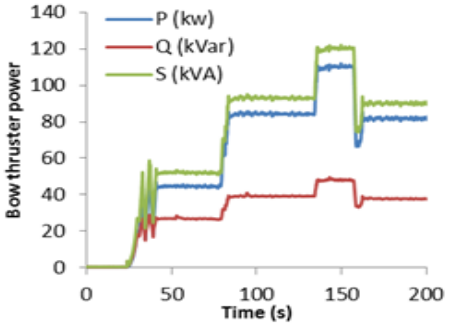

(e) generator current




(f) bow thruster current

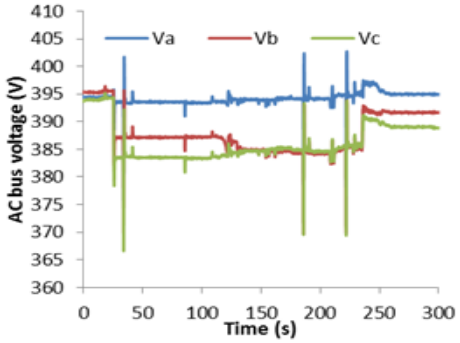



(g) generator power

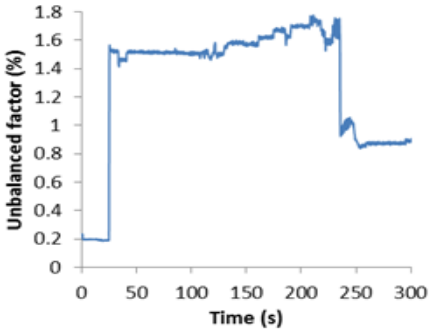



(h) bow thruster power

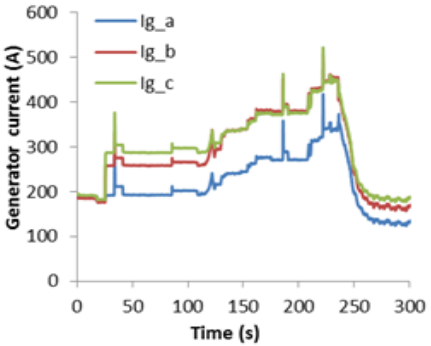
# Case B
# SPS working under unbalanced grid



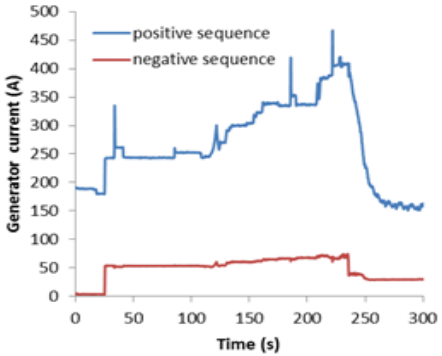

(a) AC bus voltage



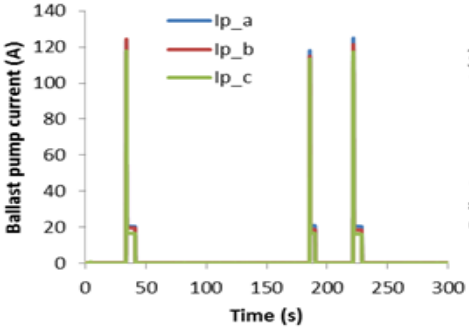

(b) unbalanced factor



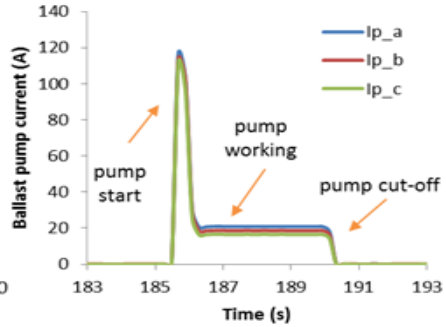

(e) generator current



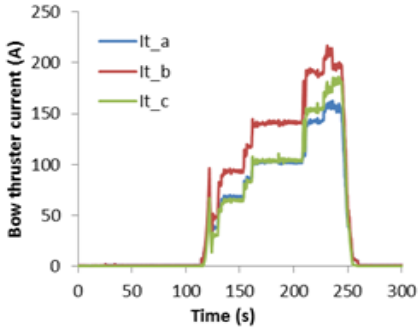

(e1) positive/negative current



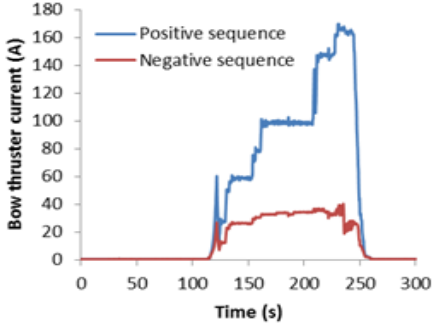

(c) pump current




(d) pump behavior



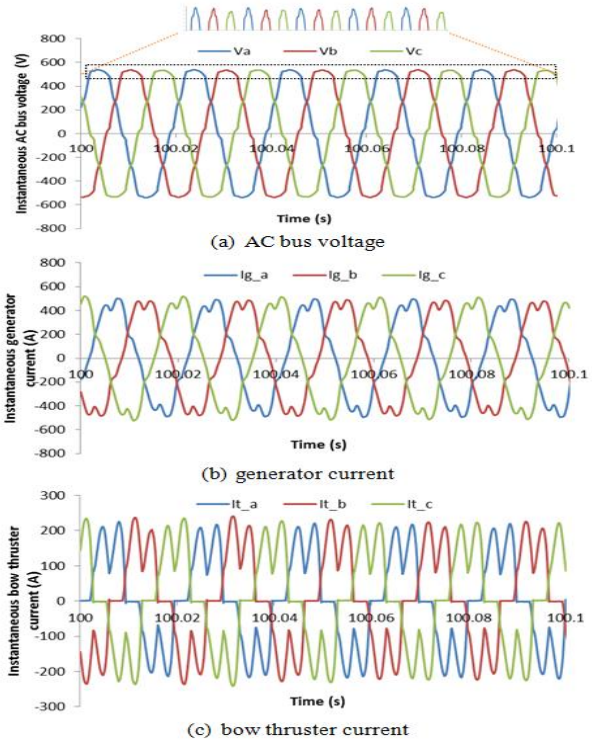

(f) bow thruster current




(f1) positive/negative current

# Comparison:

## Balanced SPS

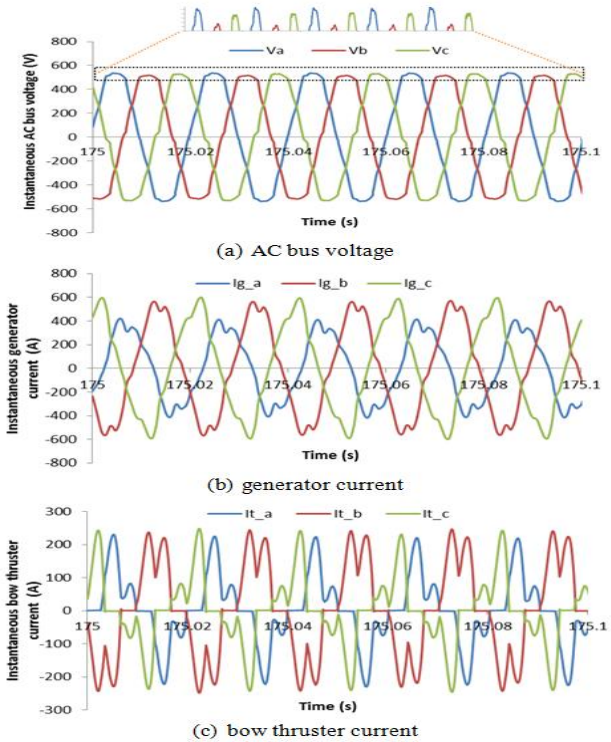



(a) AC bus voltage

(b) generator current

(c) bow thruster current

## Slightly Unbalance SPS (UF=1.5%)




(a) AC bus voltage

(b) generator current

(c) bow thruster current

# Power Quality 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**

# HyELEF project 2017

## Hybrid Electrical Ferry including Batteries

AALBORG UNIVERSITY
DENMARK

VISEDO
Electricity in Motion.

NATIONAL KAOHSIUNG MARINE UNIVERSITY 1946

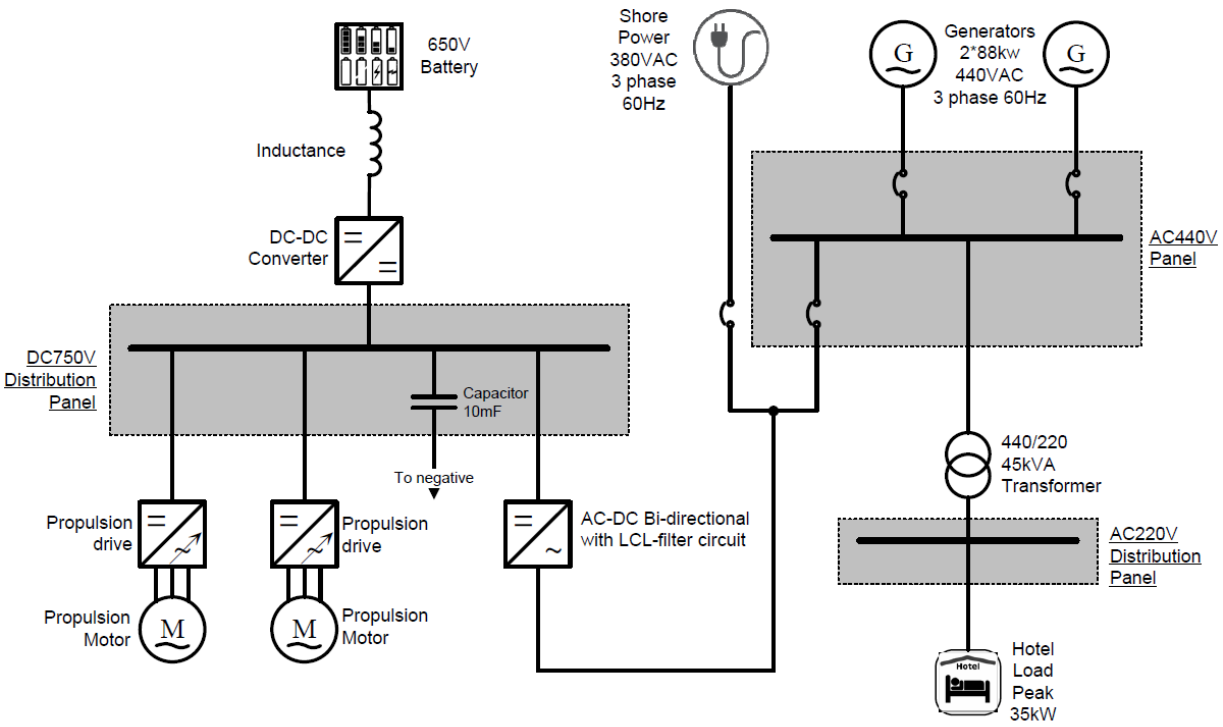
SOIC
財團法人 船舶暨海洋產業研發中心
Ship and Ocean Industries R&D Center

# Asia's First Hybrid Electric Ferry

Ferry in Kaohsiung

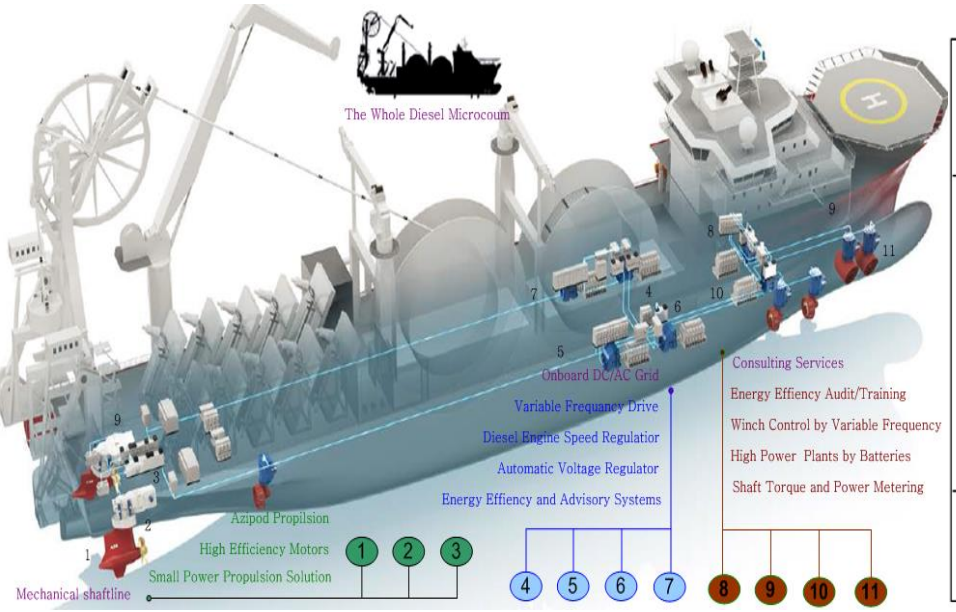
Ferry retrofitting

# Asia's First Hybrid Electric Ferry

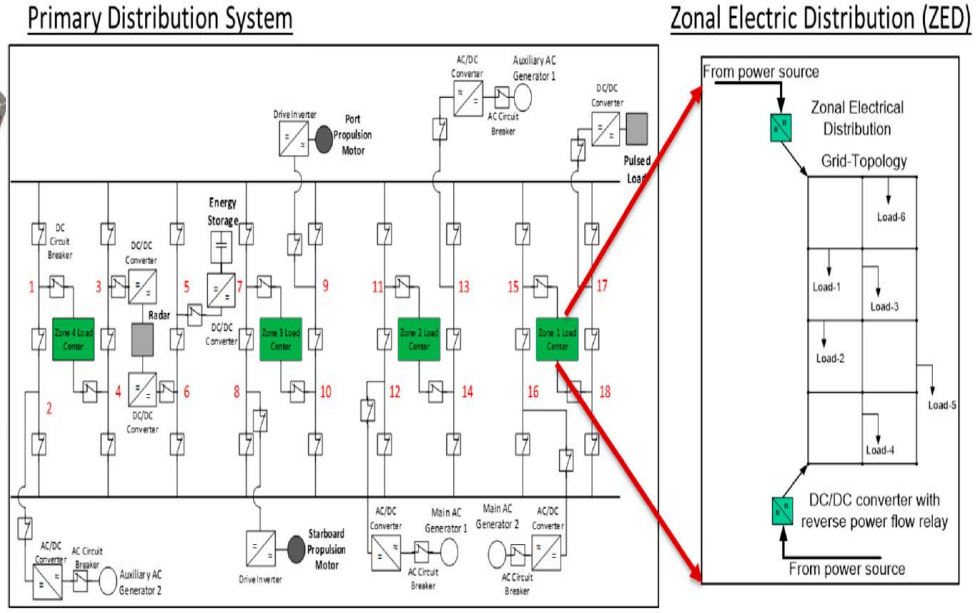


# Maritime Microgrid Lab @ AAU

## AC/DC Maritime Microgrid Systems




Intergrated Power Systems in ships



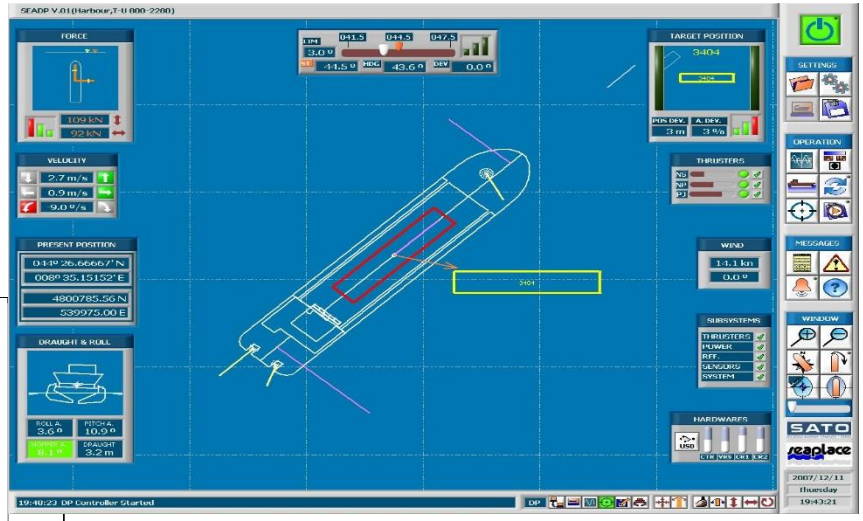

Structure of DC/AC Maritime Microgrid systems

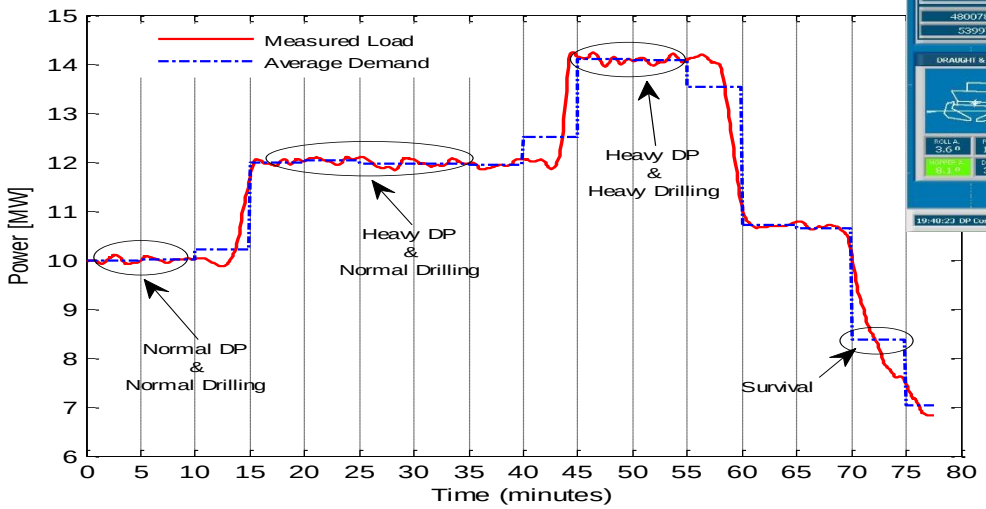
# EFFICIENSEA project 2014-2018

## Off-shore Application of the Flywheel Energy Storage System



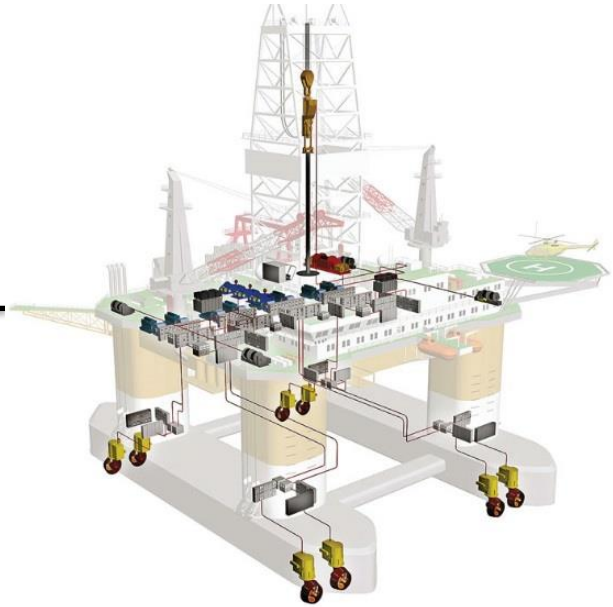

# EFFICIENSEA Project



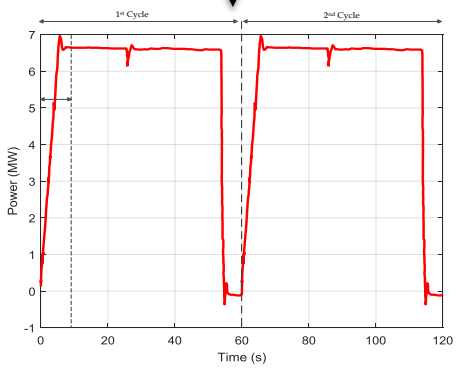



# EFFICIENSEA Project

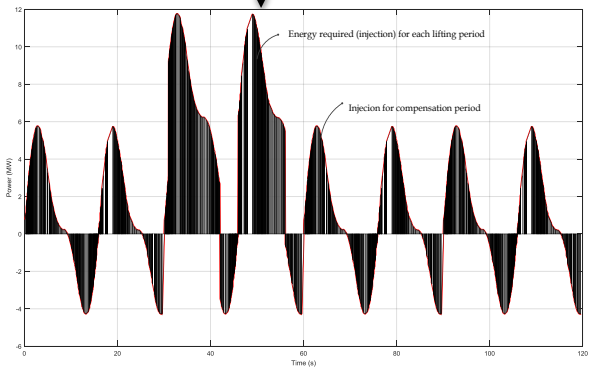
## Phase I: Study of Energy Storage Requirements



Power

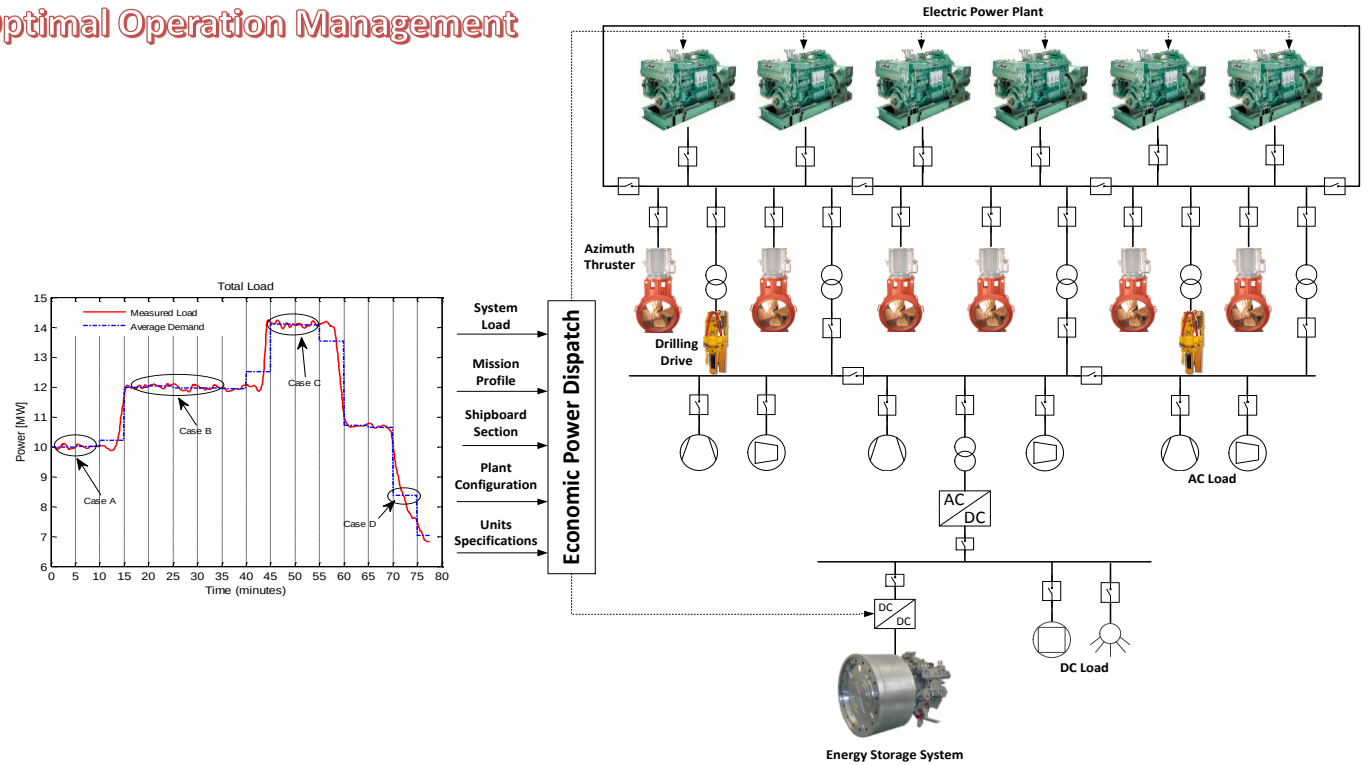



Energy

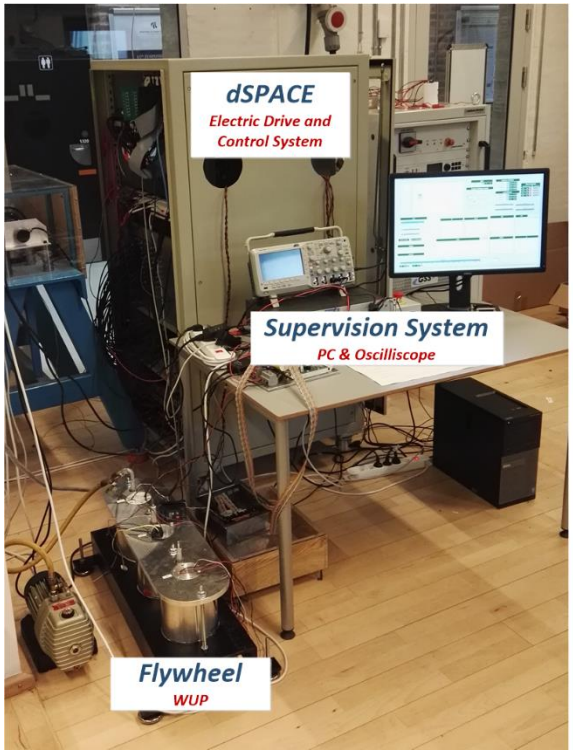


# EFFICIENSEA Project

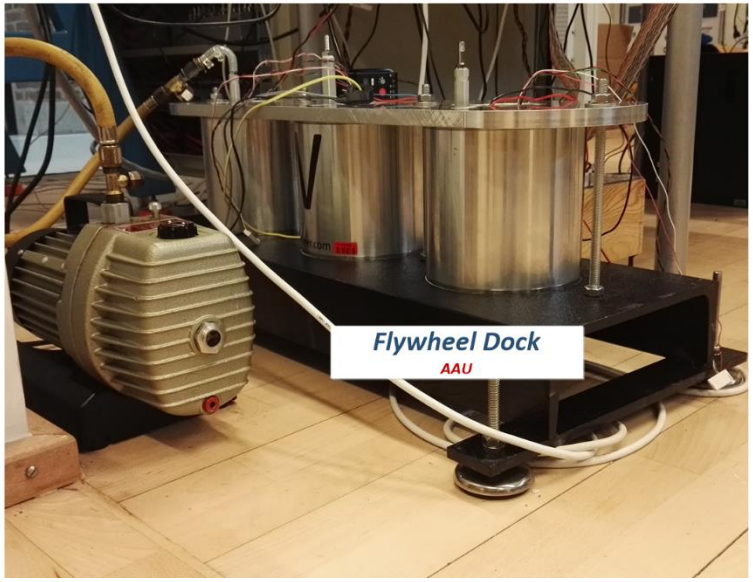
## Phase II: Optimal Operation Management



# EFFICIENSEA Project

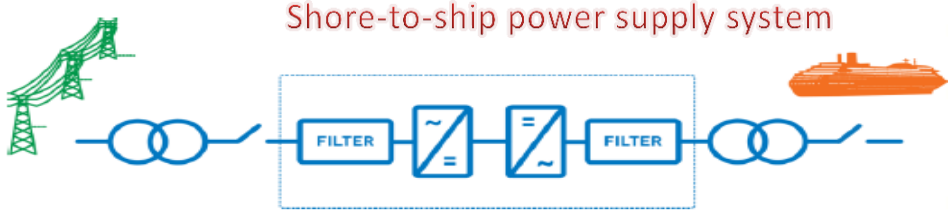


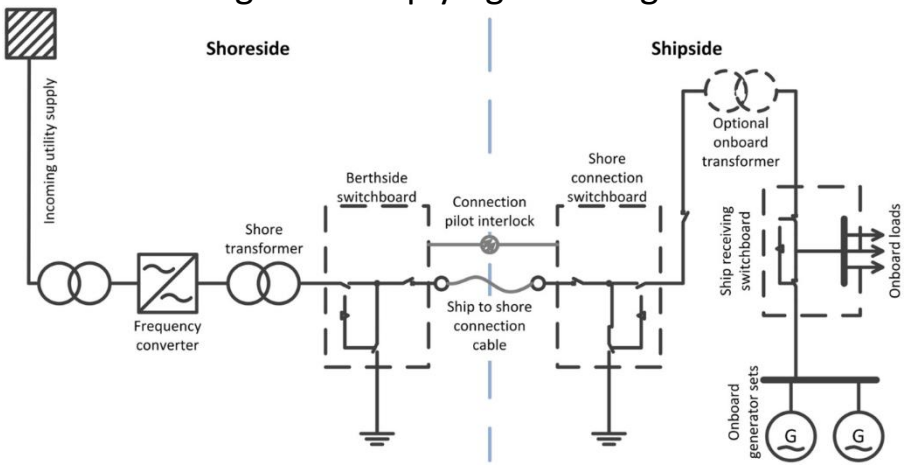

Phase III: HIL Test and Validation



# Cold Ironing

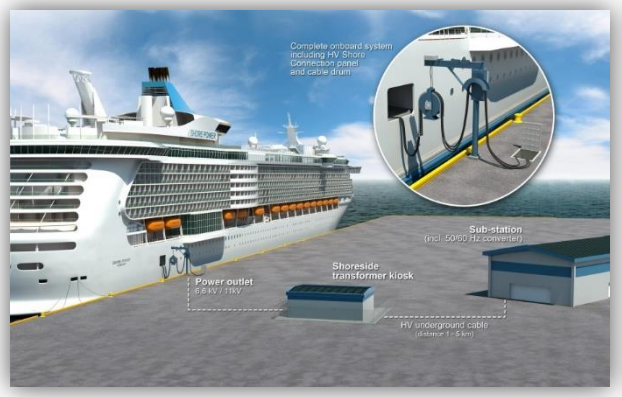
- Change grid frequency from 50Hz to 60Hz and synchronize with ships grid.
- Reduced local emissions, noise and vibrations
- Increased lifetime for ships engines
- Allow maintenance on the ships engines during the harbour stay
- Bi-directional: Generator load test power can be fed back to the shore grid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



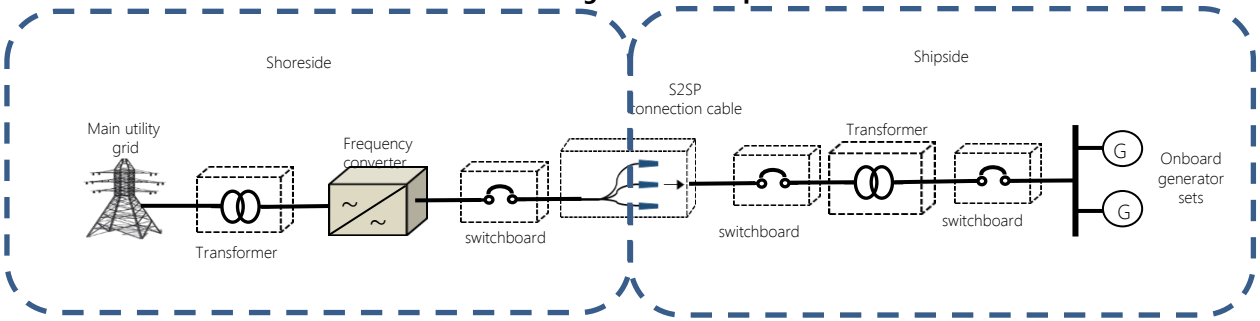




Source: Vacon Power / Danfoss

# Cold Ironing

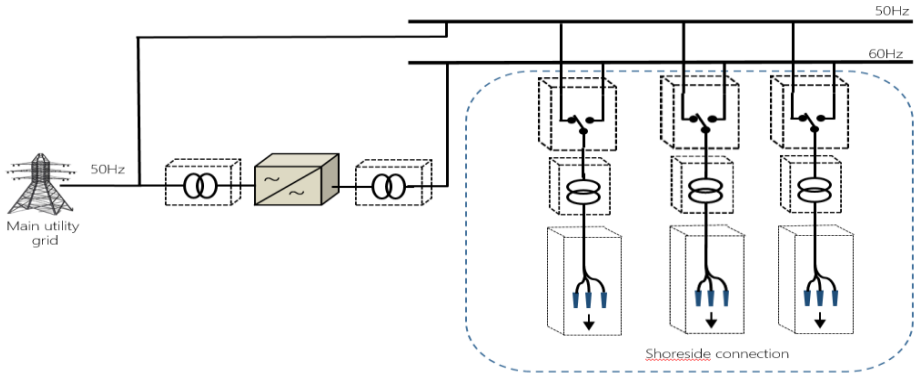



**Generic cold ironing standard requirement**



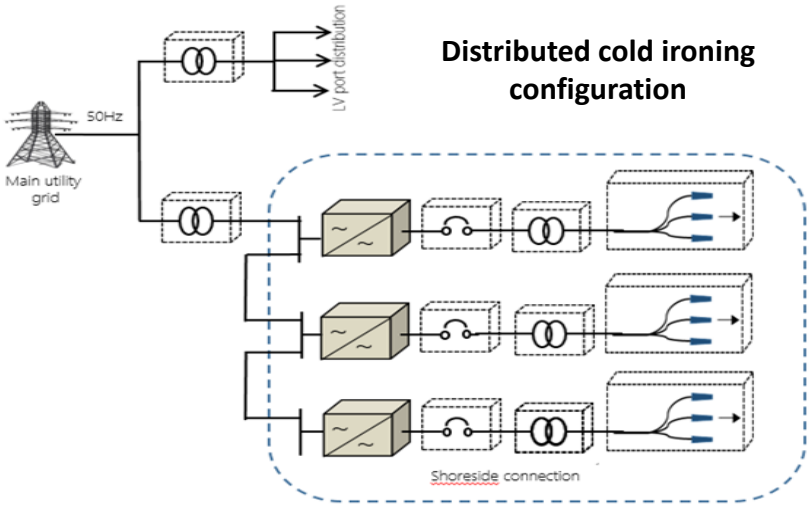
# Cold Ironing

**Centralised cold ironing configuration**




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

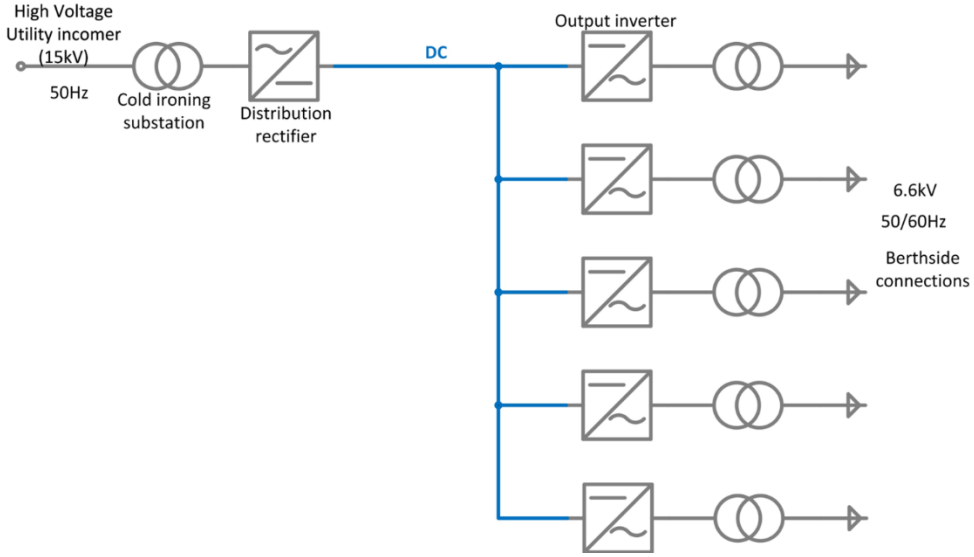
**Distributed cold ironing configuration**




- 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.

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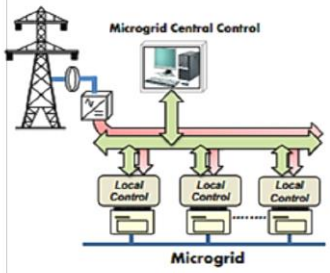


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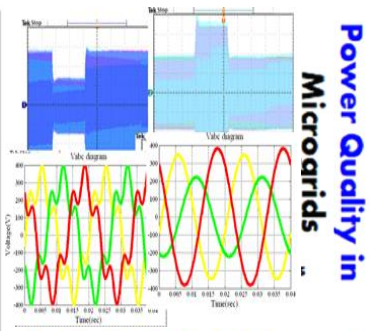

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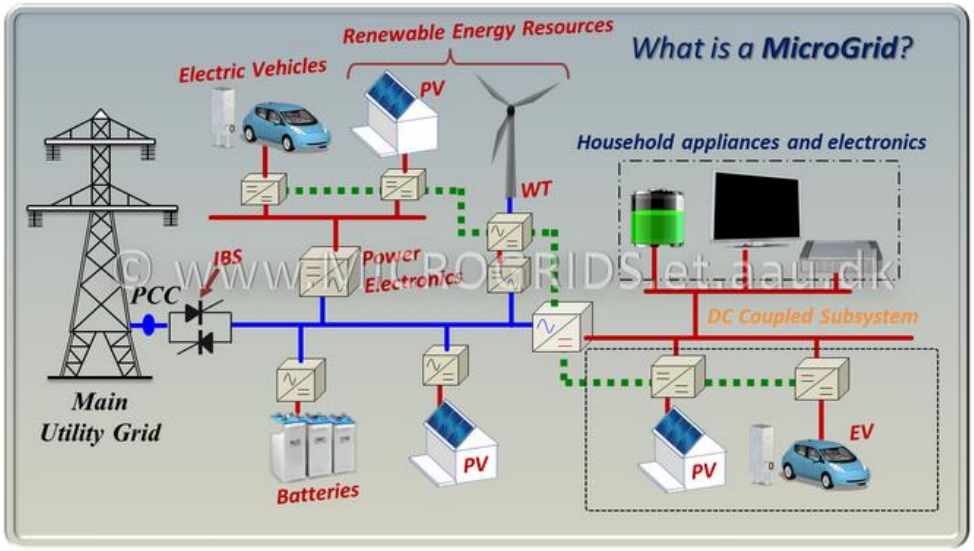
## INTRODUCTION TO THE RESEARCH PROGRAMME IN MICROGRIDS

A MicroGrid is an electrical distribution network consisted of distributed generators, local loads, and energy storage systems that can operate in grid-connected or islanded modes. Different technologies are combined together, such us power converters, control, communications, optimization, and so on. This way the energy can be generated and stored near to the consumption points, improving the stability and reducing the losses produced by the large power lines.

***Keep updated with our Microgrid research activities and projects***




***AAU Microgrid group in***

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The MicroGrid research programme areas include AC and DC MicroGrids control and management, centralized and distributed control architectures, power quality and protections, multi agent systems, standard-based information and communication technologies, online optimization techniques and energy management systems. All of the foregoing can also be conceived within a problem based learning (PBL) education for Postgraduates, PhD students and industrial partners.

The MicroGrid research programme is connected to other multidisciplinary programmes of the Energy Technology and the Electronic Systems departments at Aalborg University. The programme also promotes national and international cooperation with universities, institutions and companies.


Microgrids RESEARCH PROGRAMME

# Thank you for your attention!