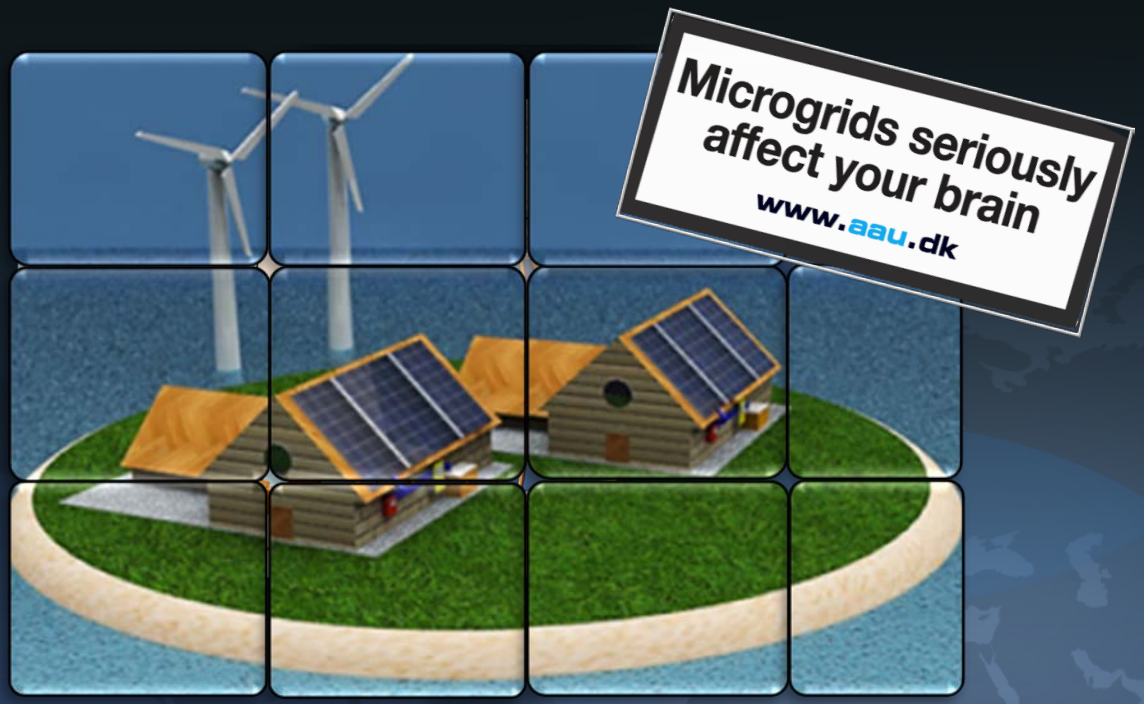


Research Challenges in Microgrid Technologies

Microgrid
Research Programme Leader

Josep M. Guerrero
joz@et.aau.dk

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

Outline

- ❑ **Microgrid Research Programme and Laboratories**
- ❑ **Microgrid Research Activities**
- ❑ **Microgrid Projects**

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 Project (PBL)** – also known as the ***Aalborg model.*** The number of students is around 15,000.

Institute of Energy Technology

ORGANISATION – DEPARTMENT OF ENERGY TECHNOLOGY

- ELECTRIC POWER SYSTEMS
- POWER ELECTRONIC SYSTEMS
- ELECTRICAL MACHINES
- FLUID POWER AND MECHATRONIC SYSTEMS
- THERMO FLUIDS
- THERMAL ENERGY SYSTEMS
- ESBJERG ENERGY SECTION

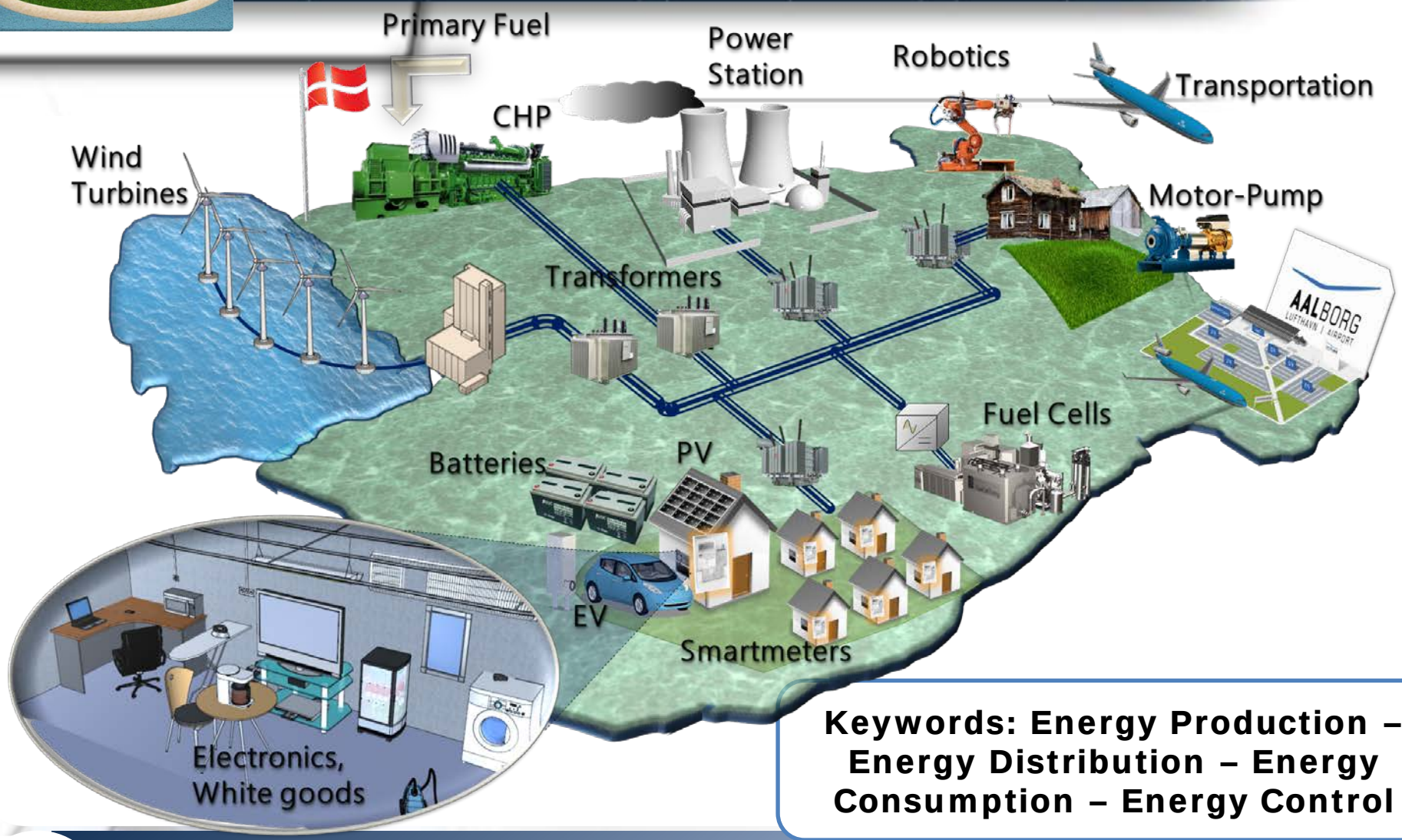
MULTI-DISCIPLINARY RESEARCH PROGRAMMES

- WIND POWER SYSTEMS
- FLUID POWER IN WIND AND WAVE ENERGY
- OFFSHORE ENERGY SYSTEMS
- BIOMASS
- PHOTOVOLTAIC SYSTEMS
- MODERN POWER TRANSMISSION SYSTEMS
- INTELLIGENT ENERGY SYSTEMS AND ACTIVE NETWORKS
- MICROGRIDS
- FUEL CELL AND BATTERY SYSTEMS
- E-MOBILITY AND INDUSTRIAL DRIVES
- EFFICIENT AND RELIABLE POWER ELECTRONICS
- THERMOELECTRICS
- GREEN BUILDINGS

DEPARTMENT ORGANISATION IN 7 SECTIONS AND 13 RESEARCH PROGRAMMES

- *Approximately 250 students*
- *Approximately 100 PhD students*
- *Approximately 40 faculty members*
- *Approximately 20 TAPs (technical administrative employees)*
- *Approximately 50% of the turnover comes from external projects*

Institute of Energy Technology



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

Microgrid Research Programme

Programme Purpose

Microgrid Research Programme **Areas**

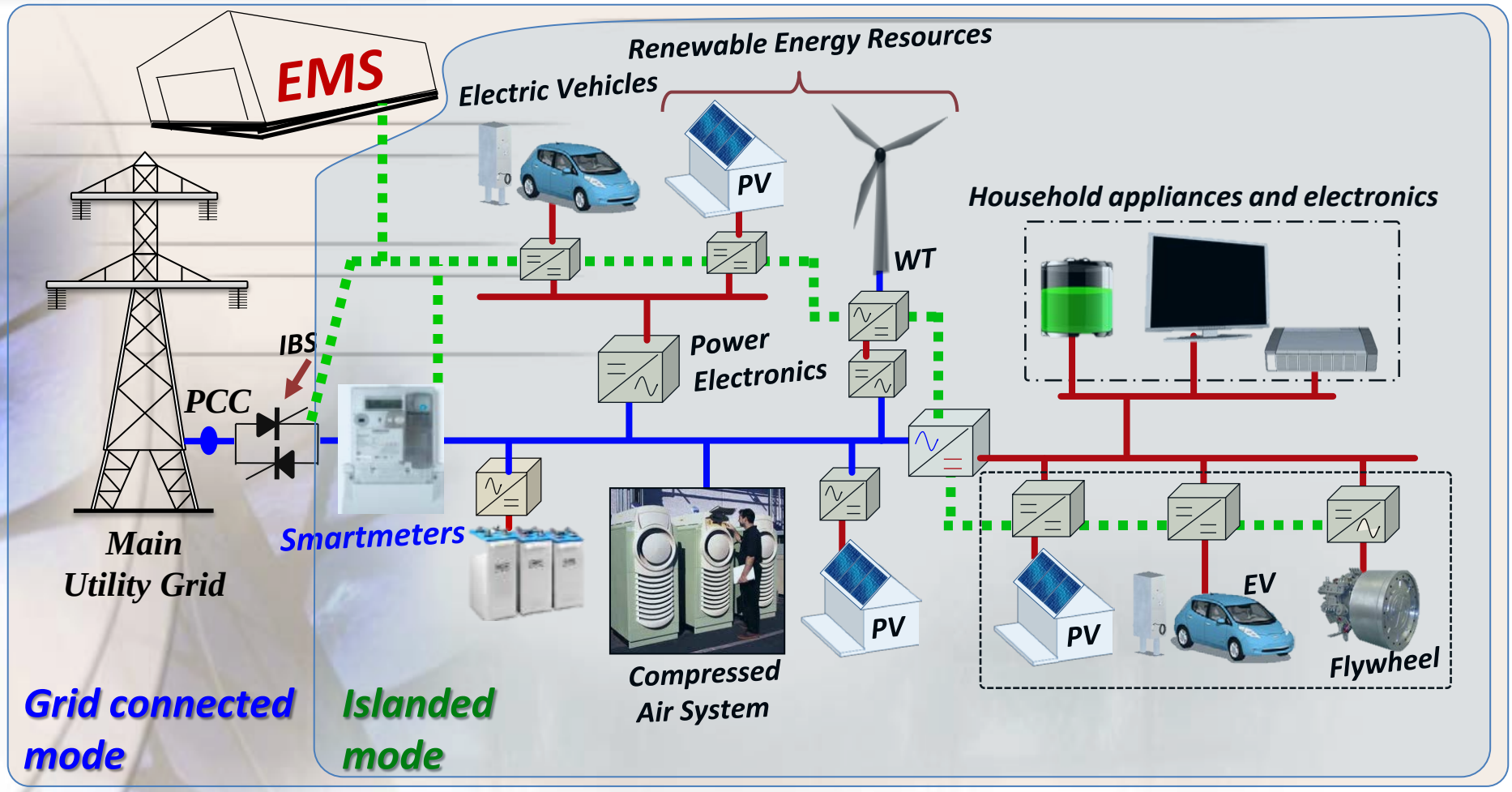
- **AC** MicroGrids
- **DC** MicroGrids

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

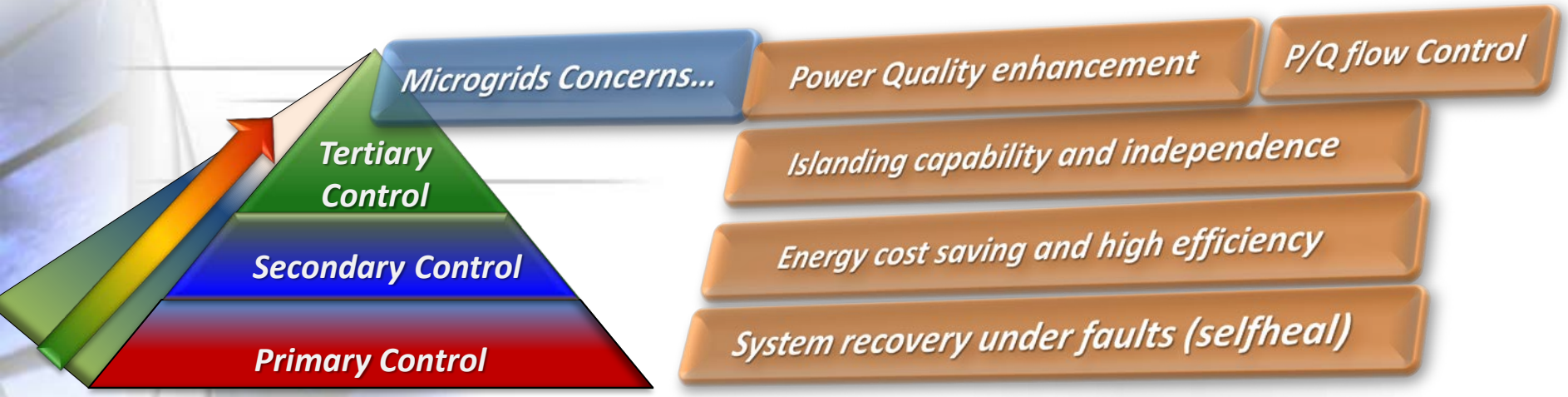
Started in 2011

The MGTeam has published more than 80 articles (mainly IEEE journals and conferences) in 2014 and about 65 articles during the first half of 2015.

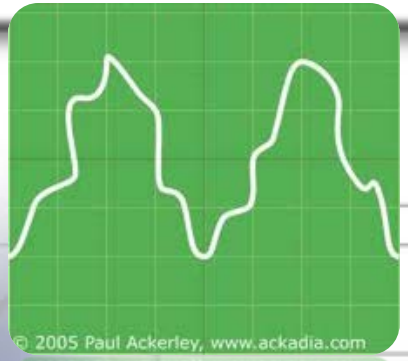
The concept of Microgrids



Hierarchical Control for MicroGrids



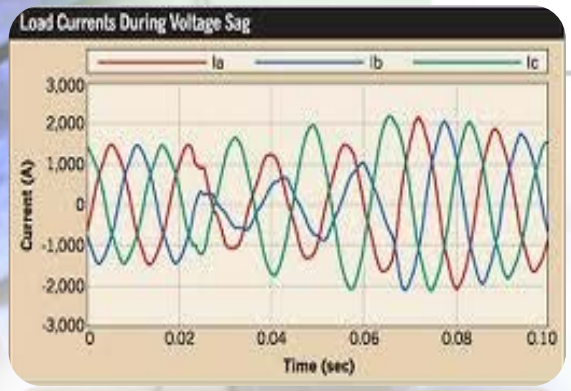
Issues in MicroGrids: *Power Quality*



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.***

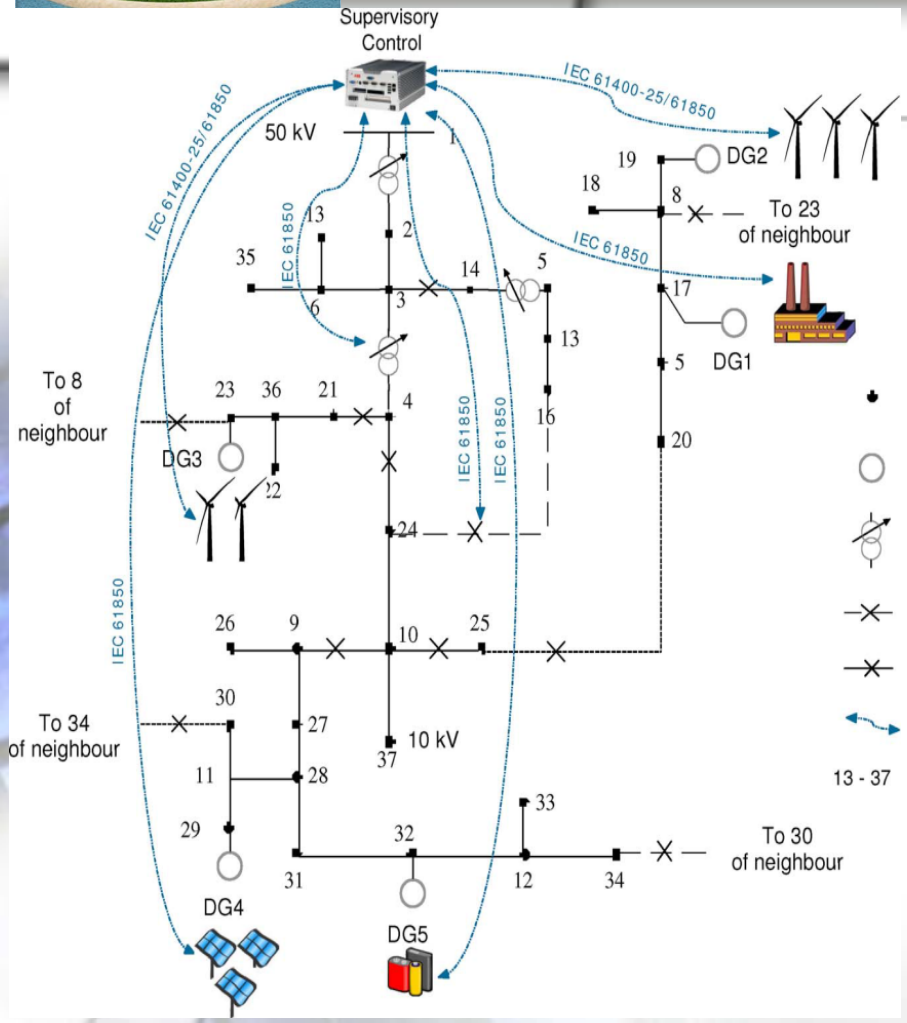
How to Coordinate harmonic/unbalance compensation?

The Whac-a-mole effect

Primary control
Harmonic virtual impedance

Secondary control
Harmonic/unbalance coordination control

Issues in MicroGrids: *Communications*

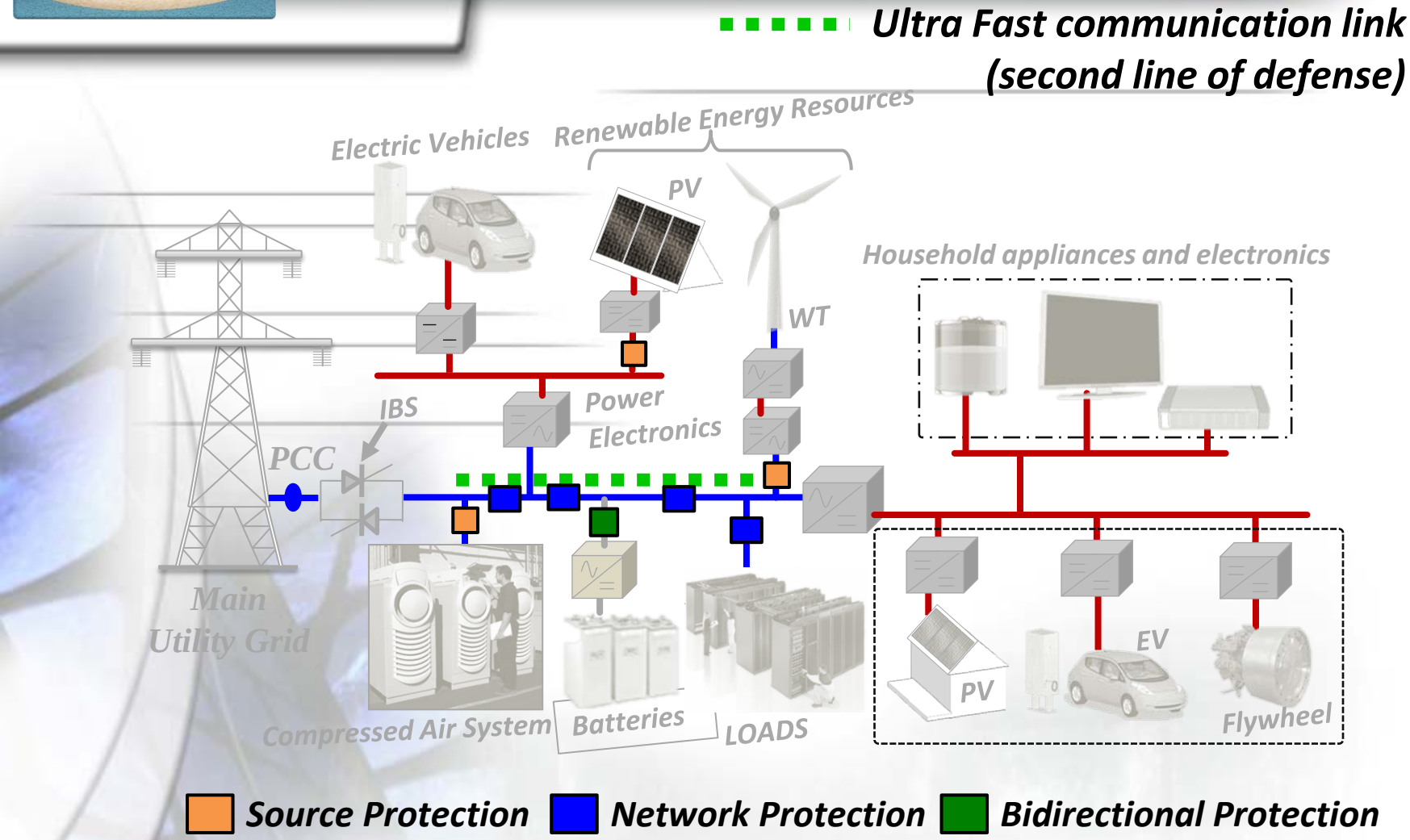


Communication model provided by ***IEC 61850 & IEC 61400-25*** to describe the physical devices in the network model.

- 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*

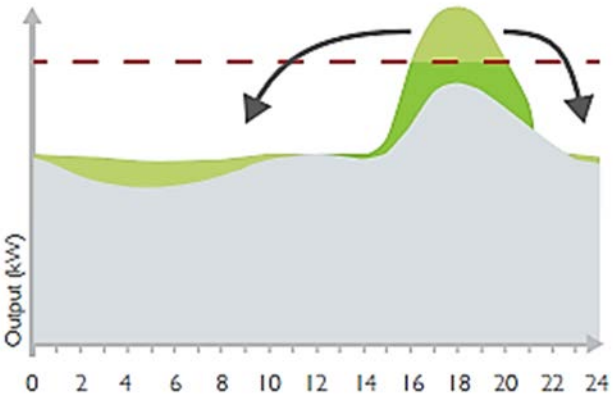


Shifting the energy paradigm

Smart Grid Strategy

Danish Ministry of Climate, Energy and Building

May 2013



Energy Sector

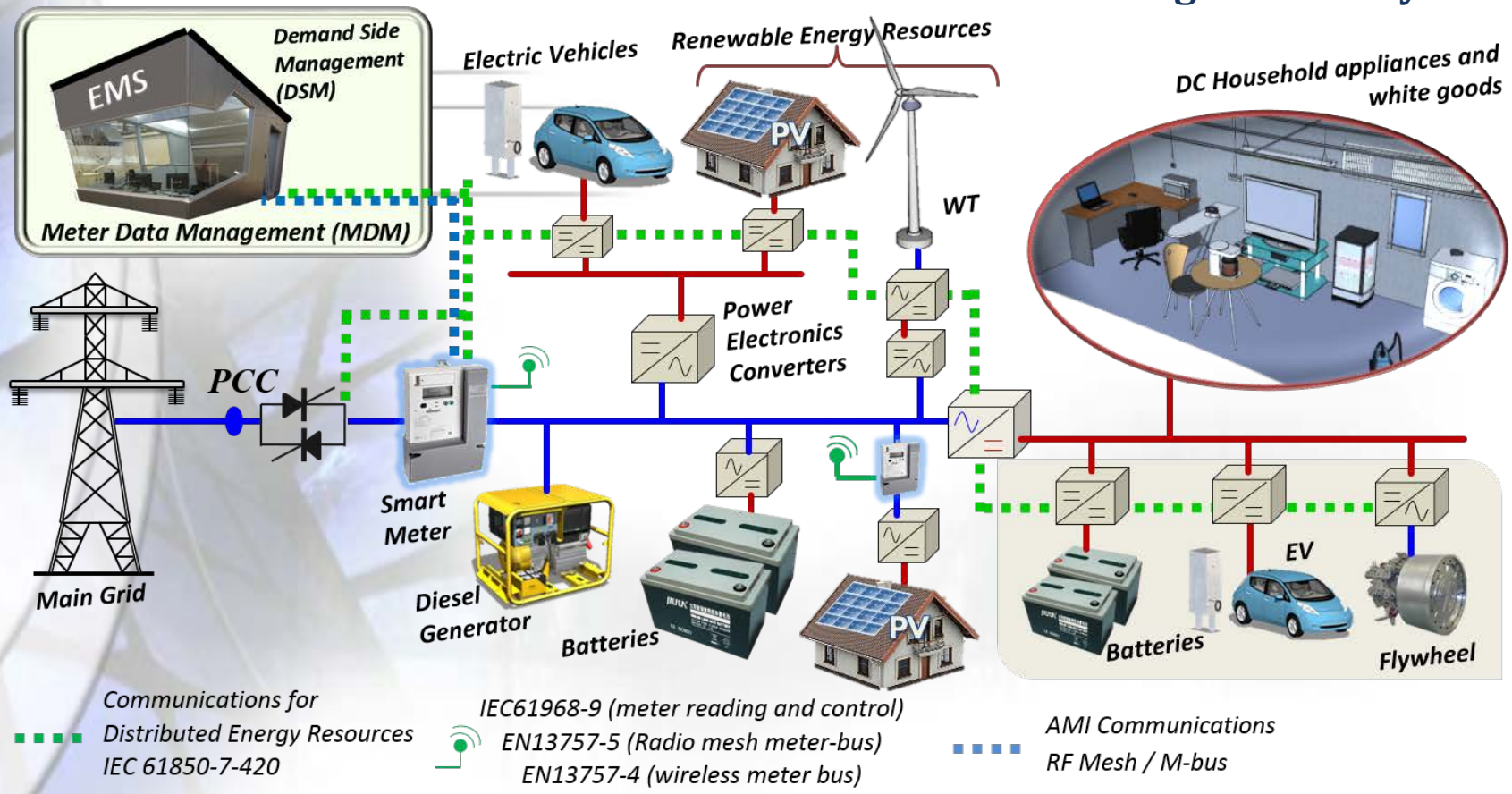
- 2013: *50% consumers remotely read hourly meters*
- 2014: *Model for hourly settle and variable tariffs*
- 2015–2020: *Wholesale and retail markets ready to manage* ***flexible electricity consumption***

Traditional consumer	*Future prosumer*
▪ Passive	▪ Active
▪ Only loads – fixed by the consumer	▪ Shiftable loads/generation
▪ No storage	▪ Storage systems/EV
▪ Electricity/thermal energy not coupled ▪ Manual management	▪ EMS take care of global energy objectives
▪ Load-dependent power quality	▪ Power quality system control
▪ Unidirectional power flow	▪ Bidirectional power flow according to energy hourly pricing, etc.
▪ Considers only local residential energy	▪ Considers both local-residential and global-neighborhood energy requirements

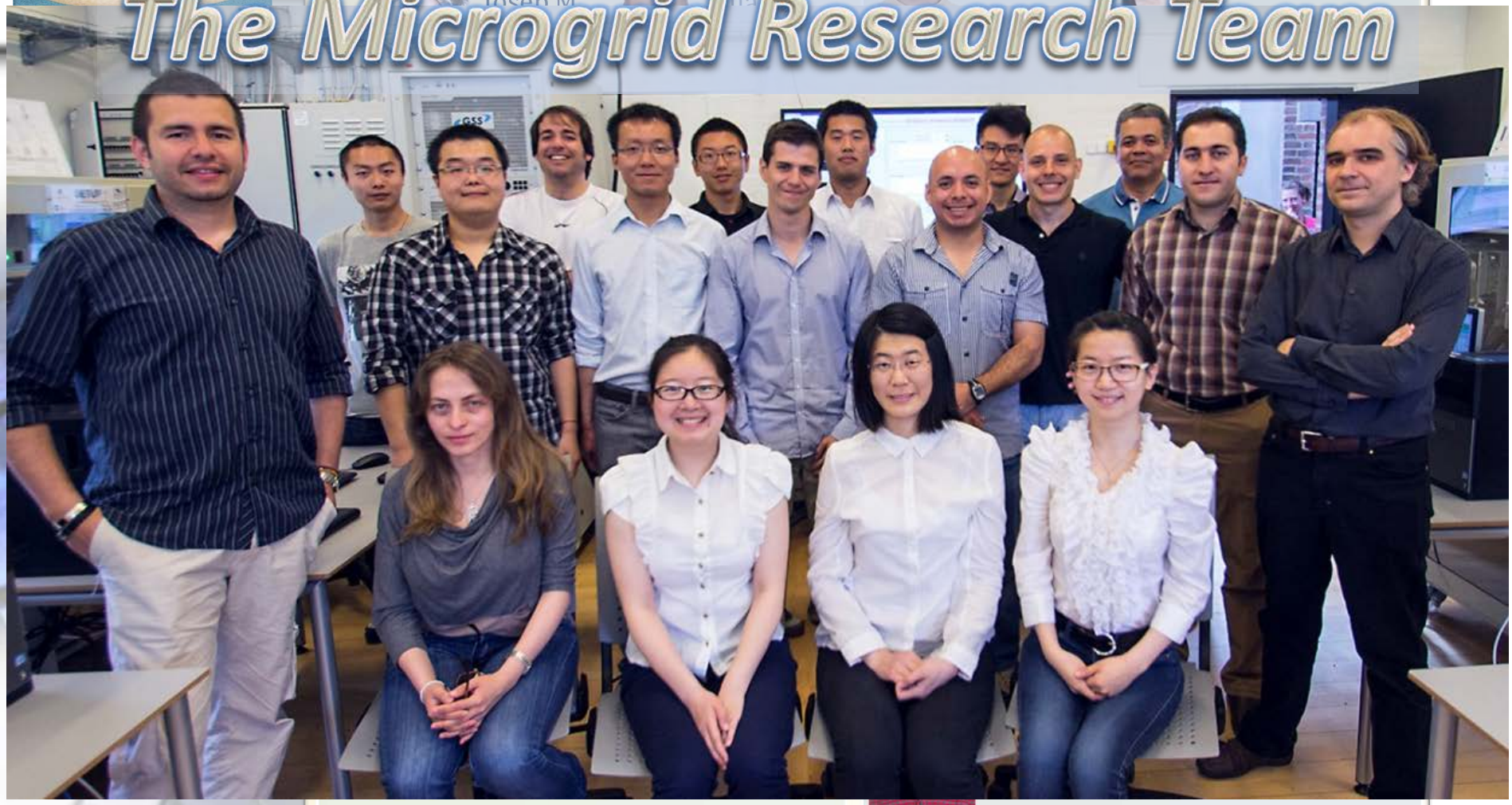
MICROGRID RESEARCH PROGRAMME

5 Years Road Map

- ✓Microgrids and minigrids in emergent countries and rural areas
- ✓AC and DC grids for ships and aircrafts
- ✓AC/DC microgrids protections
- ✓DC microgrids and DC homes
- ✓AMI for AC/DC microgrids
- ✓MV microgrids and Hybrid ESS



The Microgrid Research Team



Microgrid Research Team

Programme Coordinators

Josep M

PhD students

Dan Wu
Primary Control

Yajuan Guan
Ancillary services for MGs

Microgrid Research Laboratory

MicroGrids RESEARCH PROGRAMME

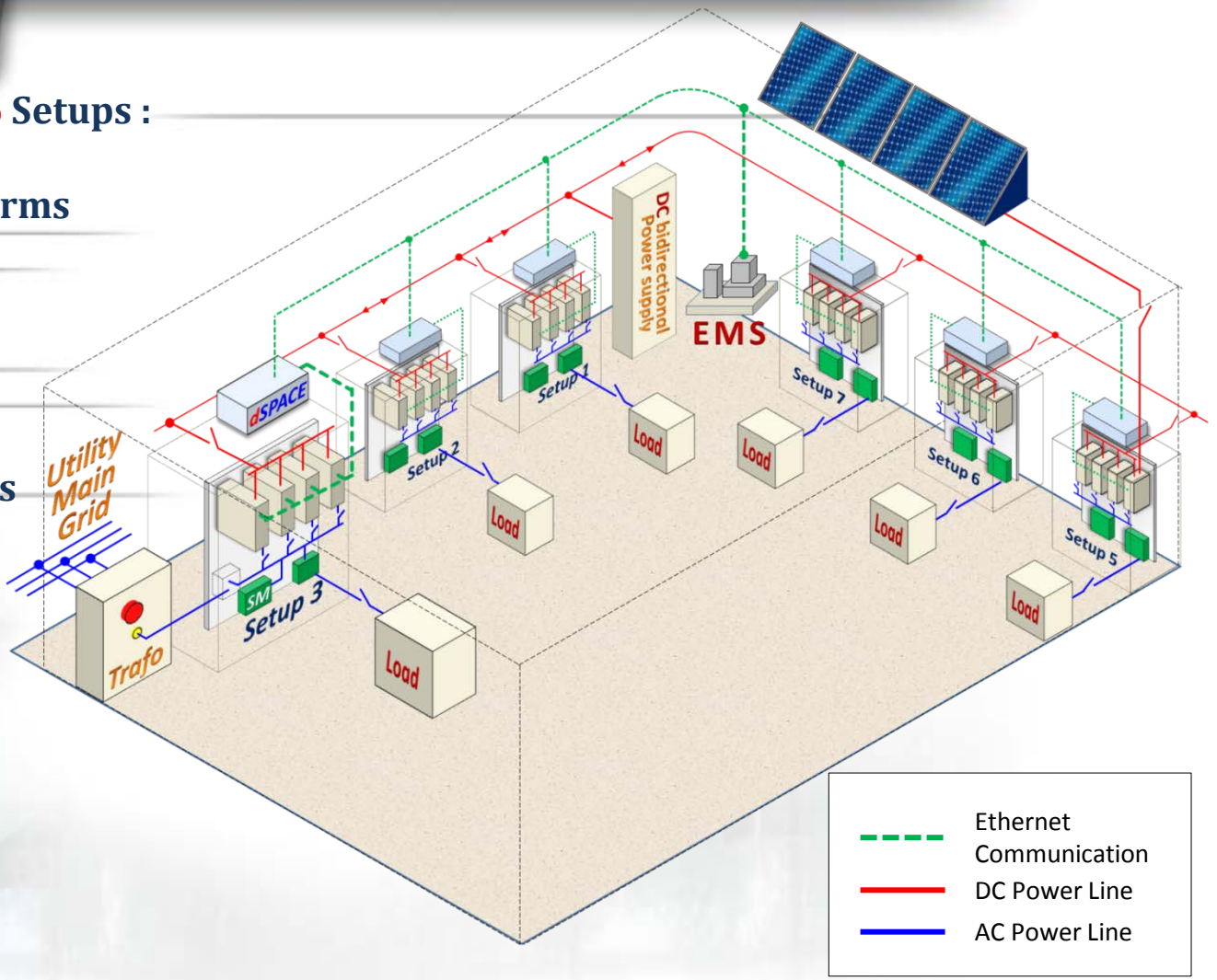
Microgrid Research Laboratory

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

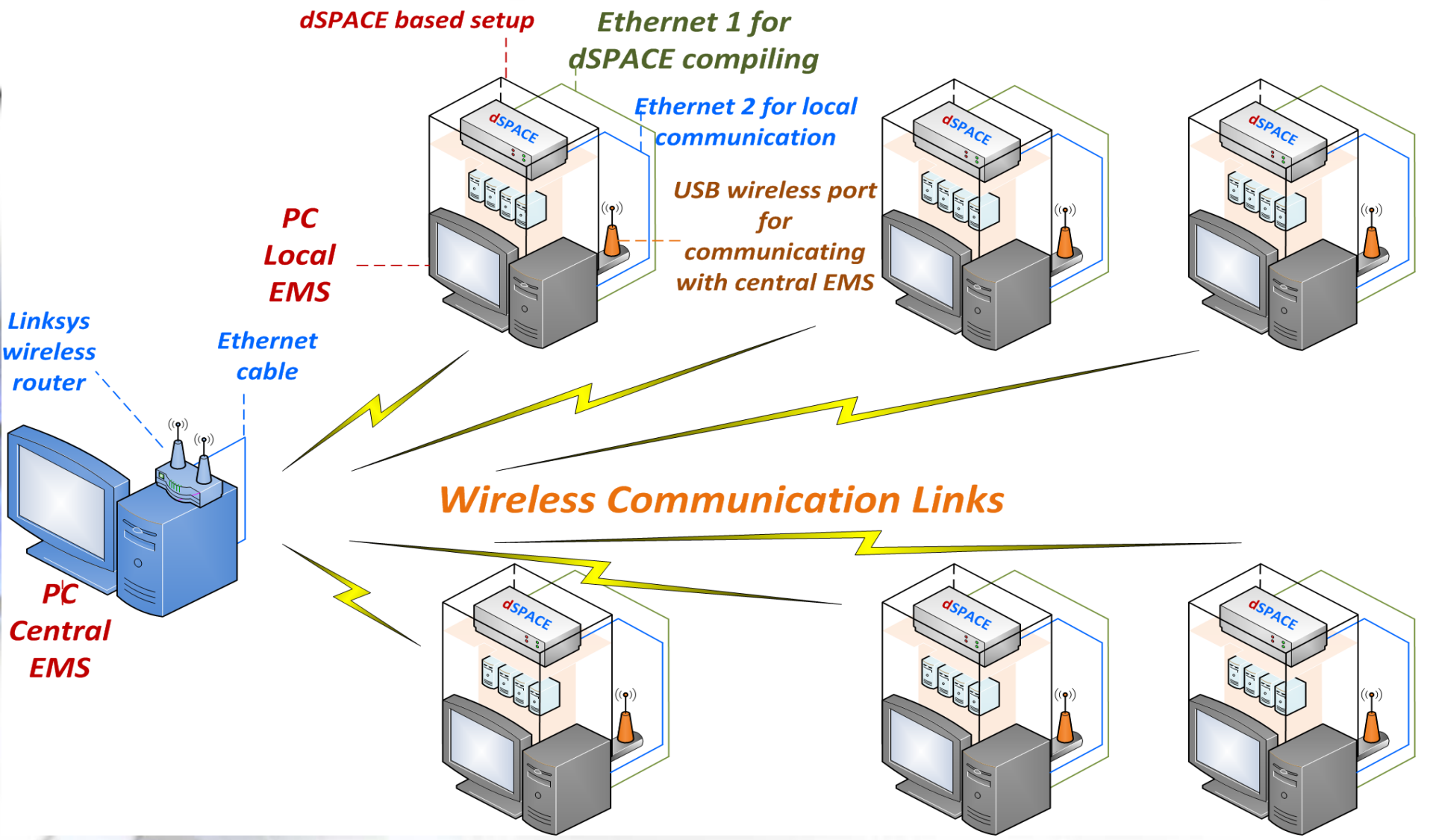
Microgrid Research Laboratory

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



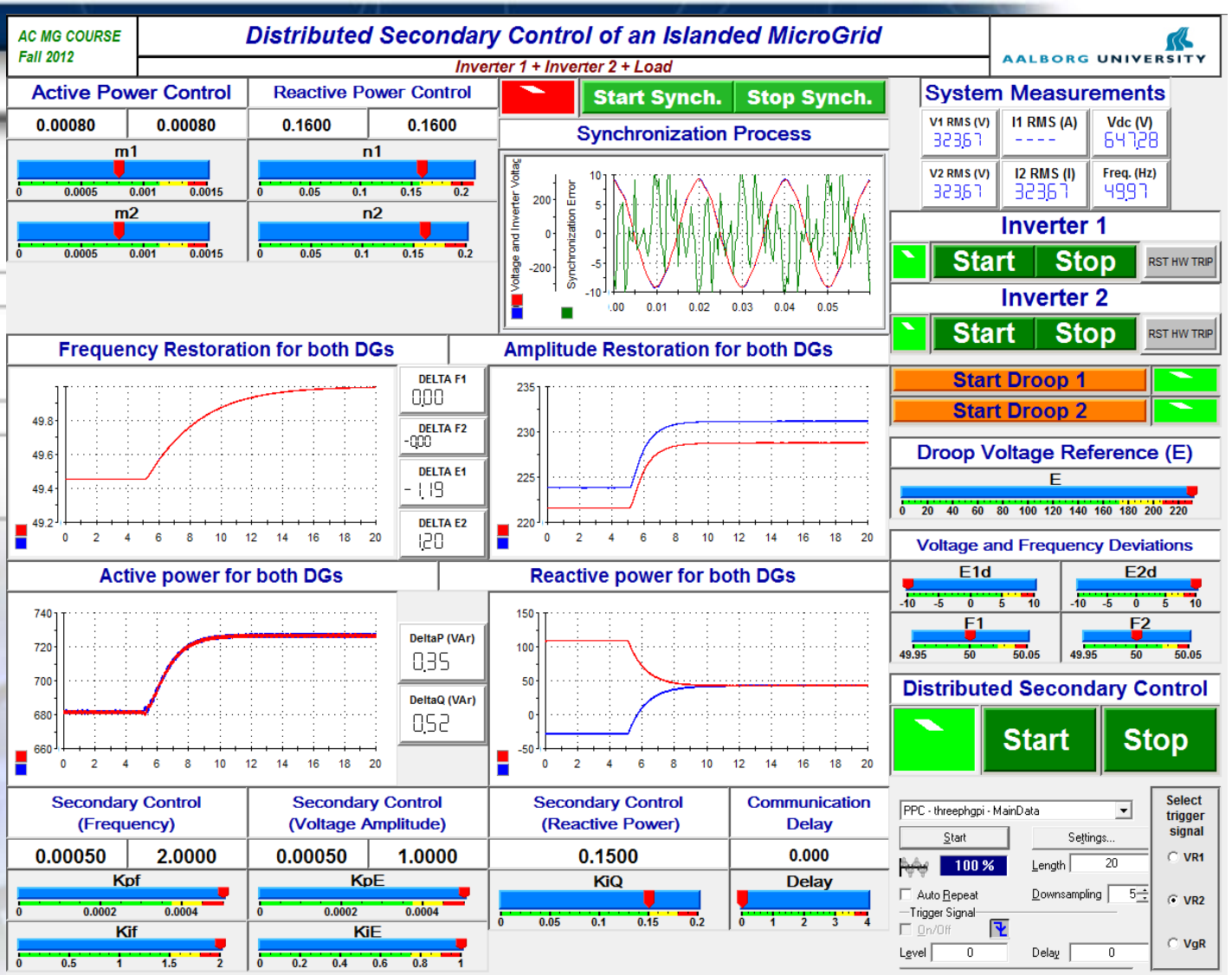
Microgrid Research Laboratory



Experimental test - DSPACE 1006

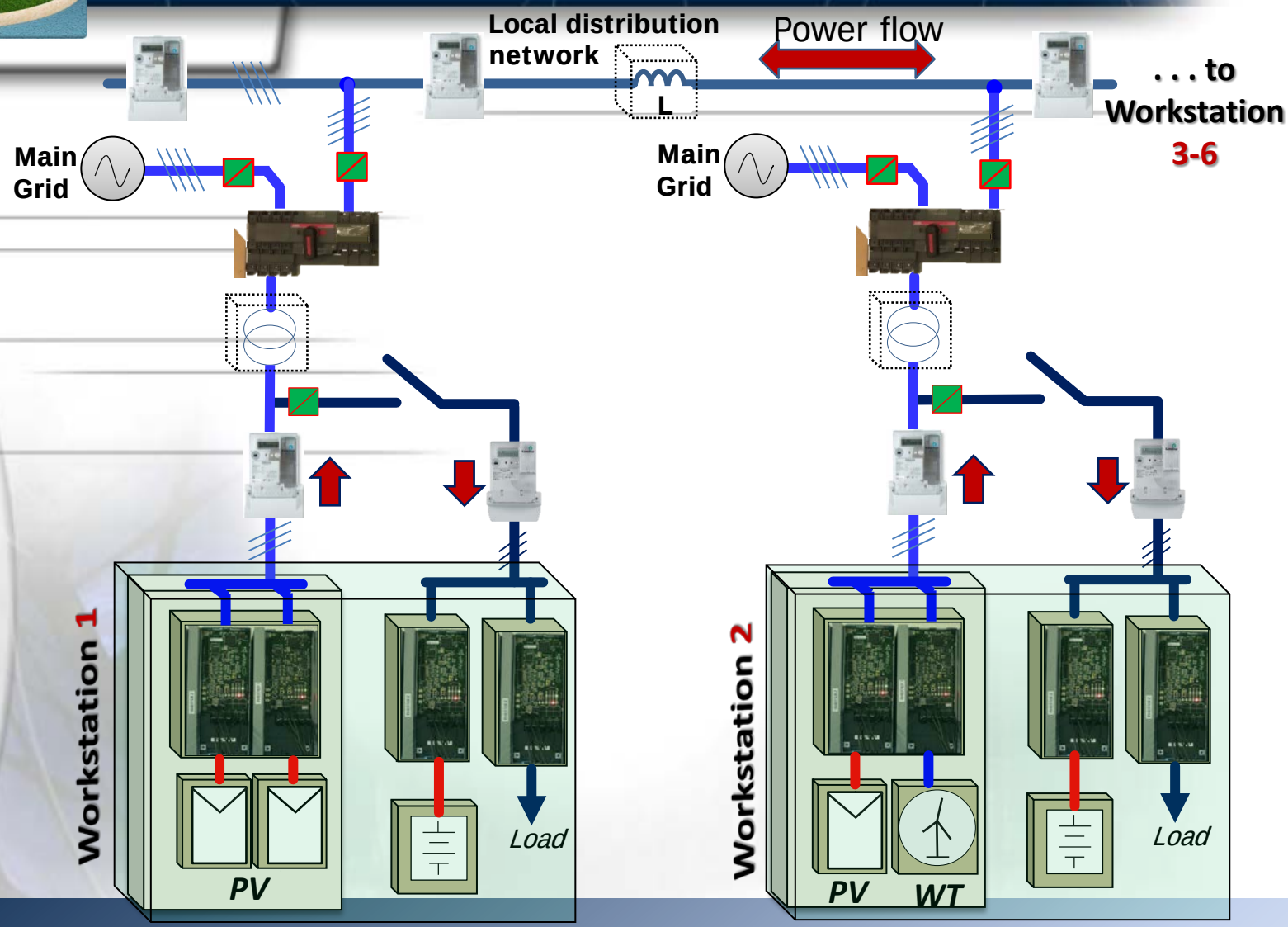
Real-time control and monitoring platform through *Control-Desk*

Electrical schemes from Matlab simpowersystem library are directly compiled into C code and downloaded to the dSPACE



Microgrid Central Controller – EMS in labview

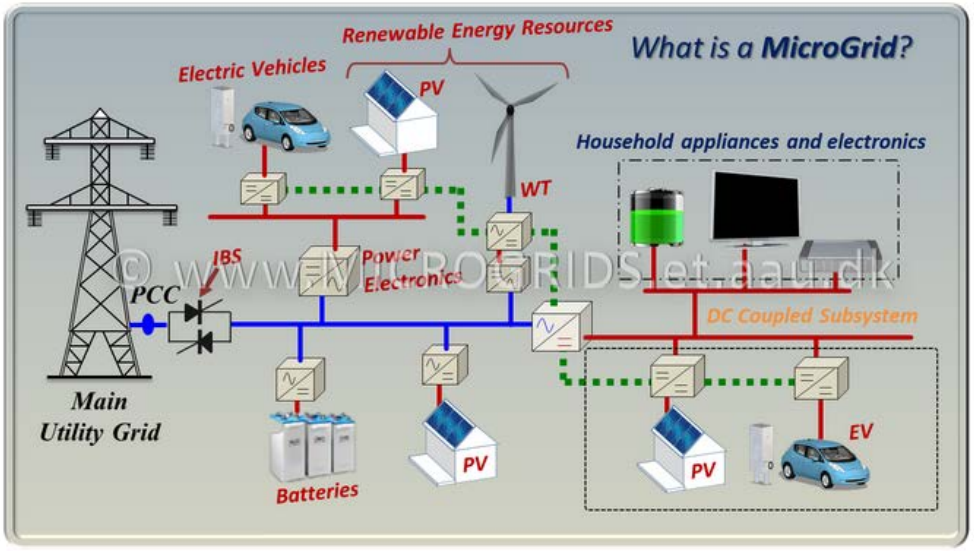
Experimental Test



www.microgrids.et.aau.dk

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.



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.

Keep updated with our Microgrid research activities and projects

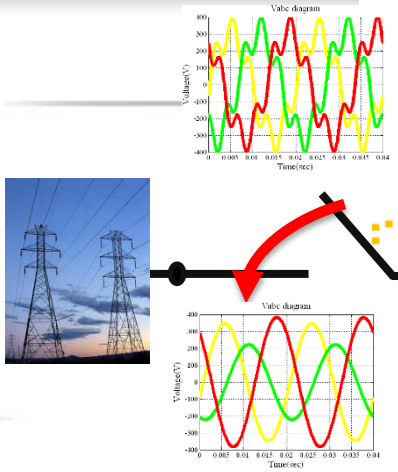
AAU Microgrid group in LinkedIn

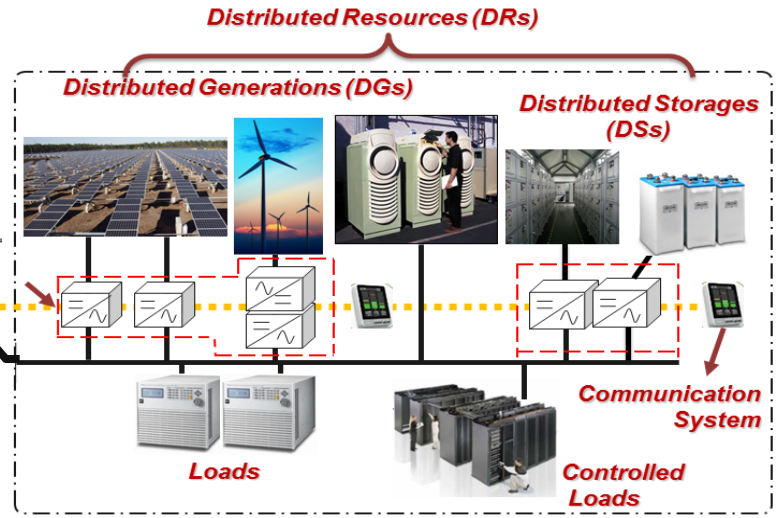
Outline

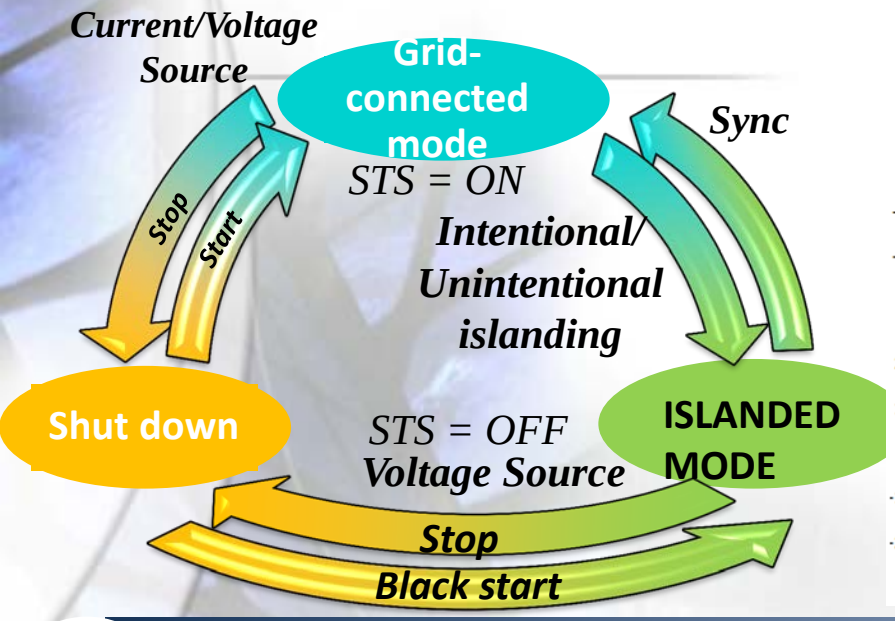
- ❑ Microgrid Research Programme and Laboratories
- ❑ Microgrid Research Activities
- ❑ Microgrid Projects

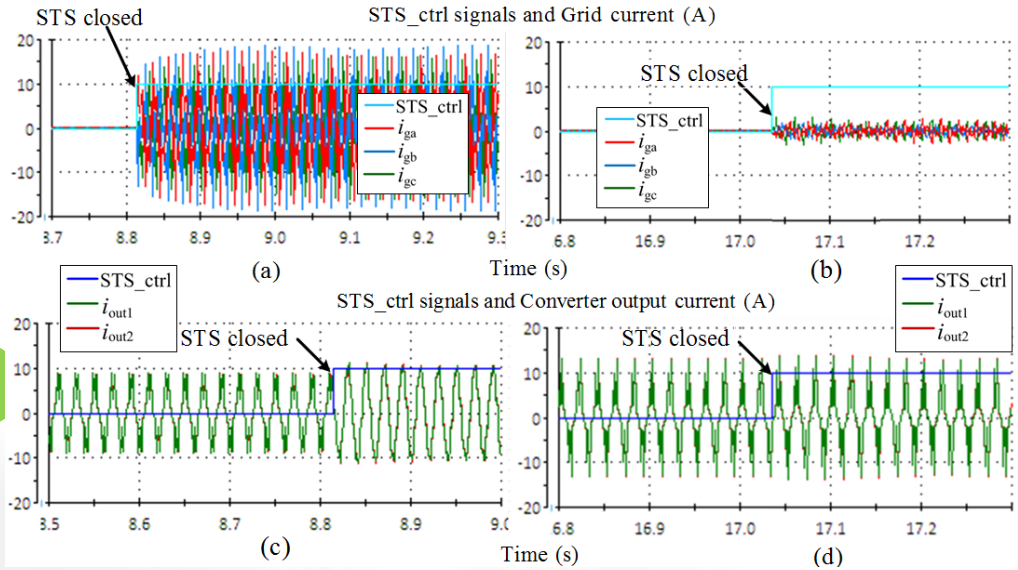
Microgrids Research

Distributed Active Synchronization for Microgrid under Unbalance and Harmonic Distortions





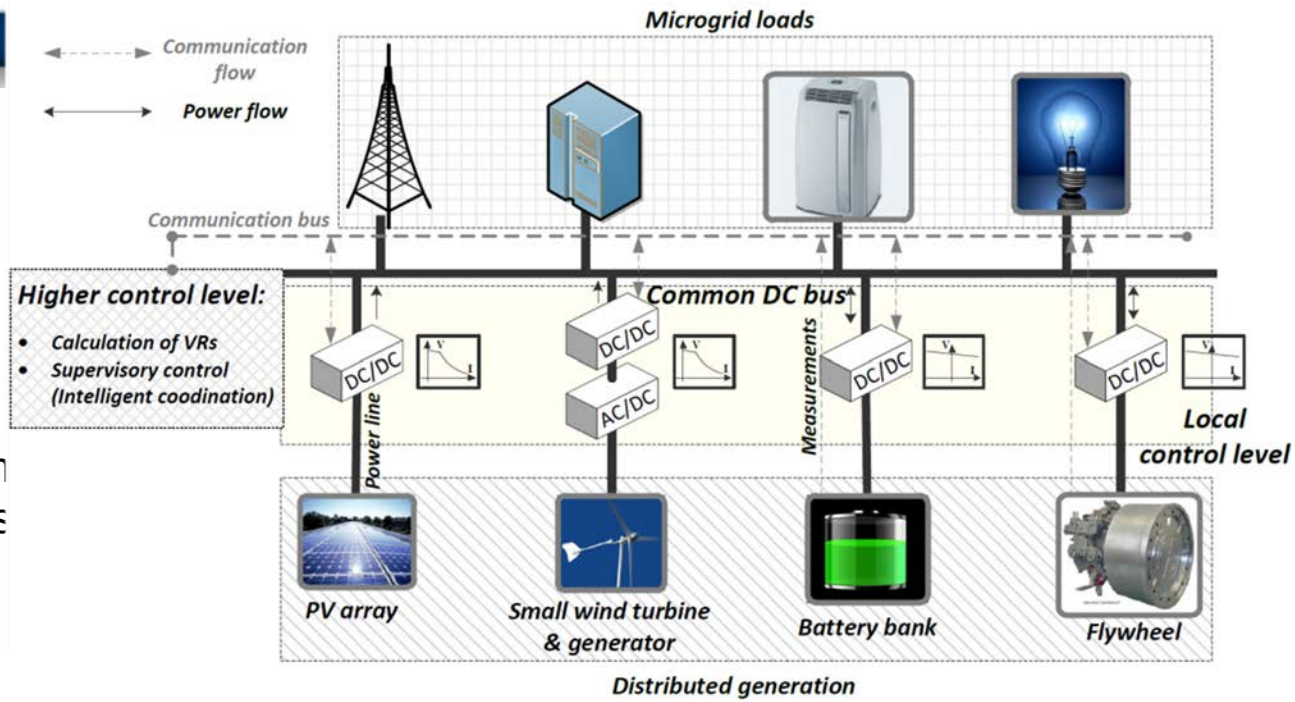


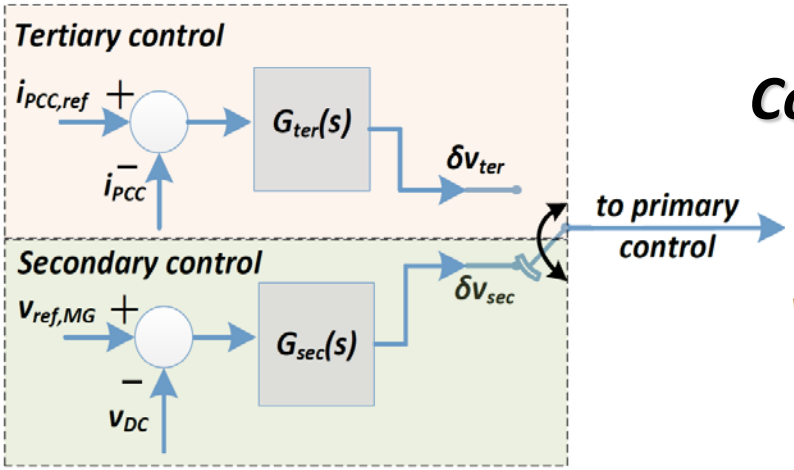


Microgrids Research

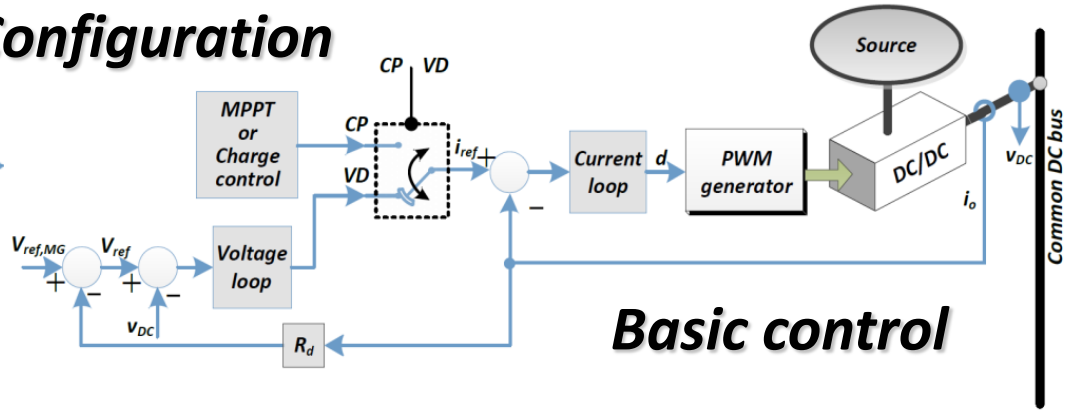
DC Microgrids Operation and Control

- Remote **telecom** application
- **Coupled** renewable systems
- DC **powered homes**
- Fast **HEV** charging stations



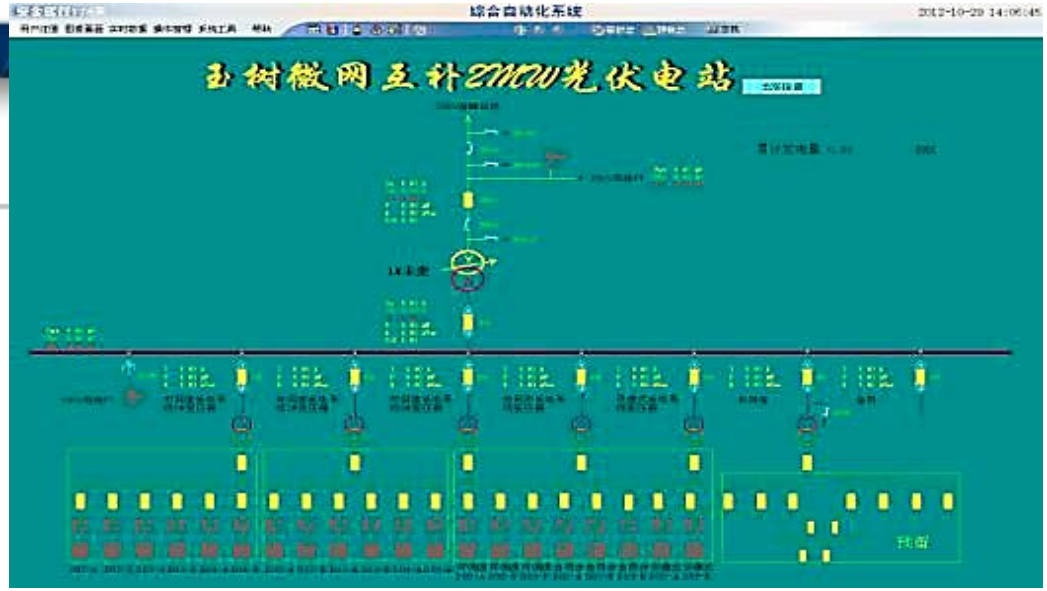


Configuration



Basic control

PV Microgrid in China



Tens of Demonstration Microgrids Constructed

- Voltage Levels 380V; 10kV
- Installed Capacity 1MW;
  1MW - 5 MW;
  5 MW – 50 MW;

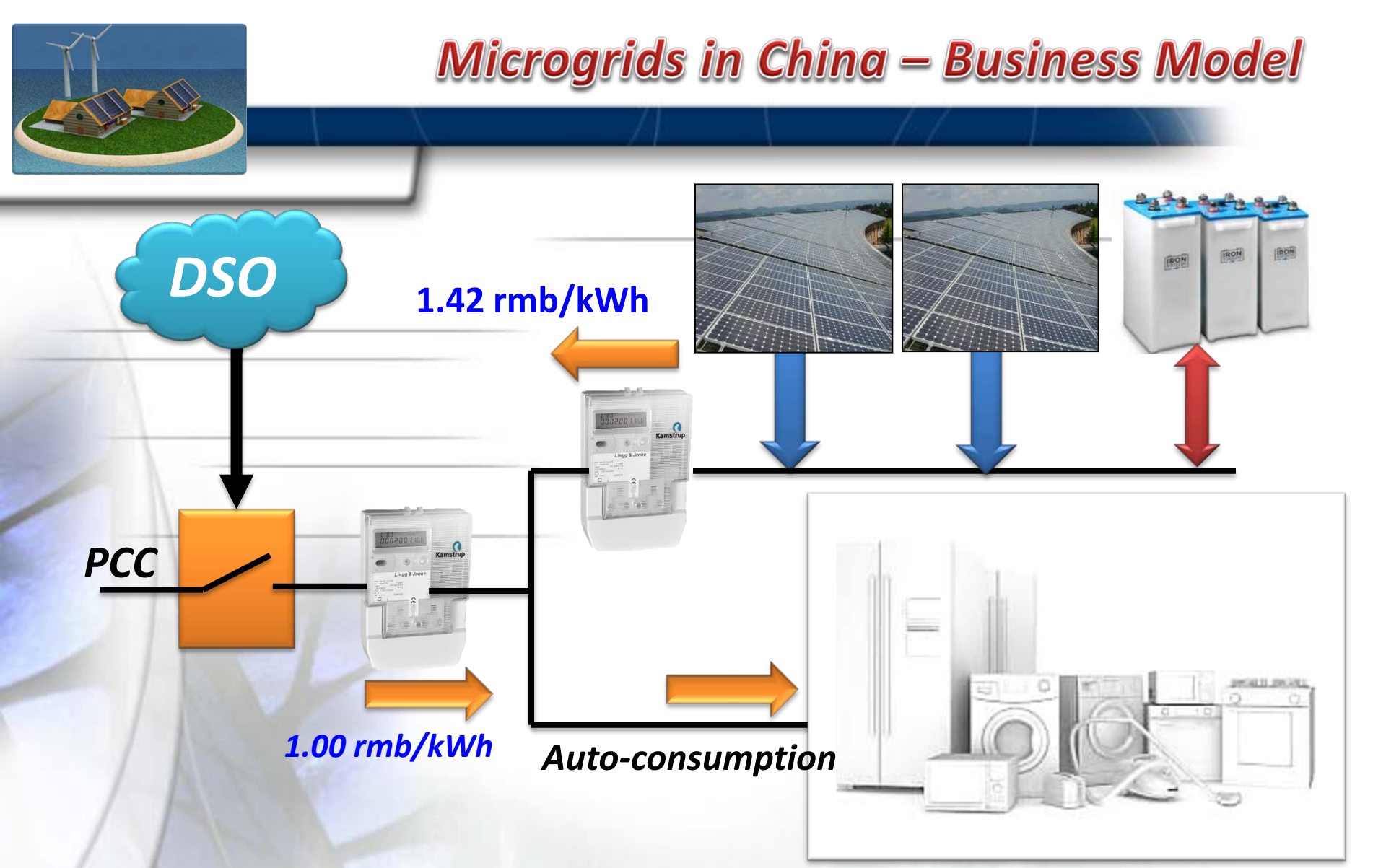
2 MW
PV Microgrid@Yushu

Microgrids in China – 30 MicroGrids

"12th Five Years" period in China 30 microgrid demonstration projects :
10 islanded microgrid demonstrations
20 grid-connected microgrid demonstrations

= 30 Microgrid demonstration Total Power: 1.2 GW

Microgrids in China – Business Model



EUDP Sino-Danish project

MicroGrids RESEARCH PROGRAMME

Micro-Grid Technology Research and Demonstration

Josep Guerrero, AAU.
Mehdi Savaghebi, AAU
& Kai SUN, Tsinghua U.

AALBORG UNIVERSITY DENMARK

Kamstrup

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

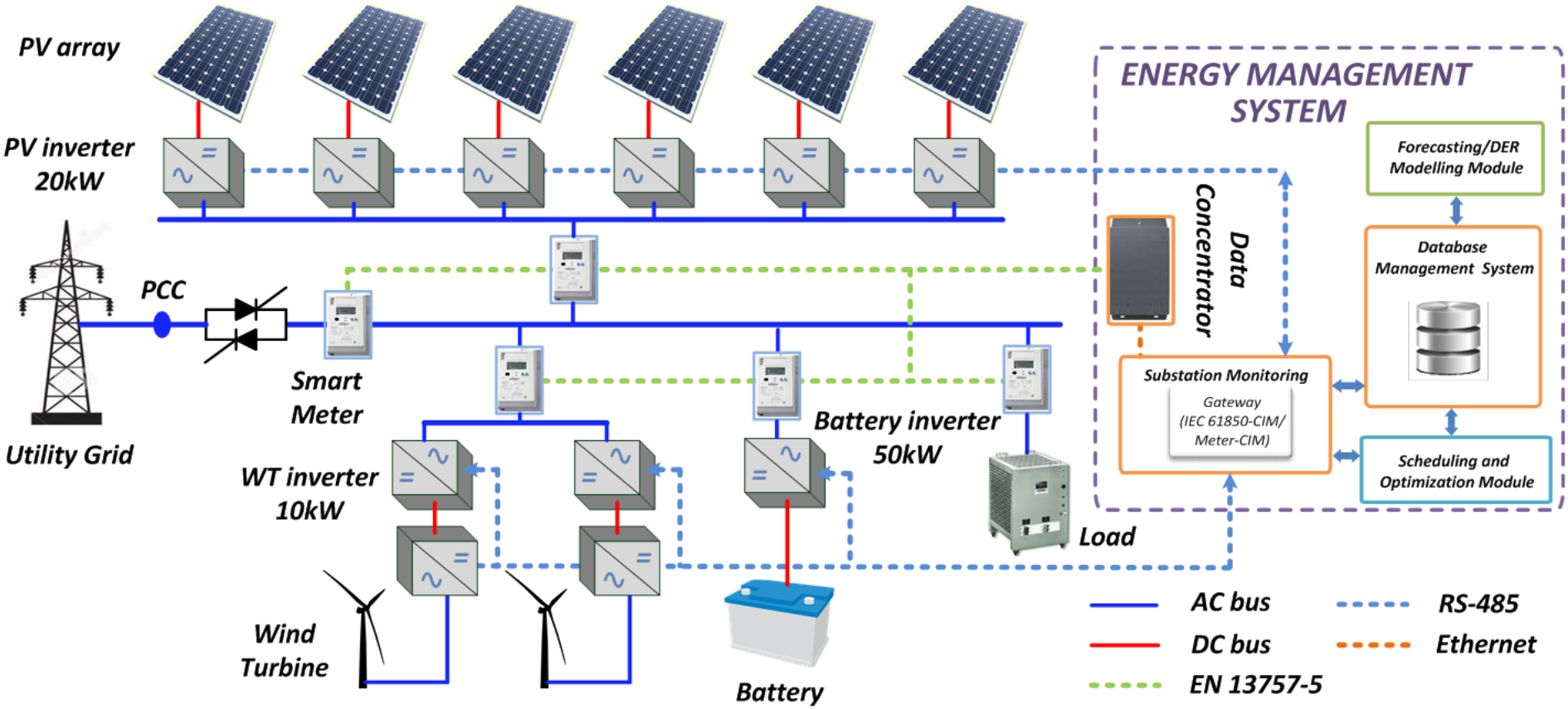
清華大學
Tsinghua University

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



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.

Satellite vertical view of Plant B

East-west span of Roof is 105 meters, and the north-south span is 98 meters, with a roof area of about 10,000 square meters.

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

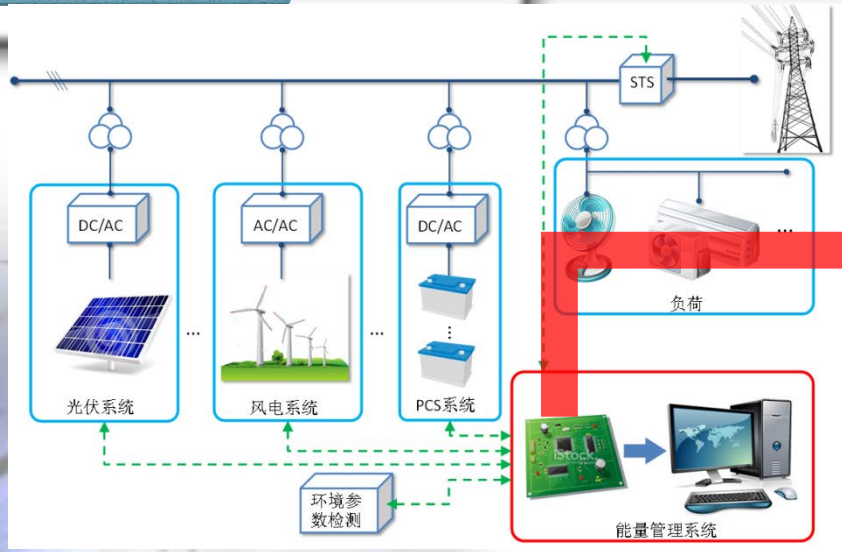
50kVA Bi-Directional Converter + Lead-Acid battery

Operation modes:

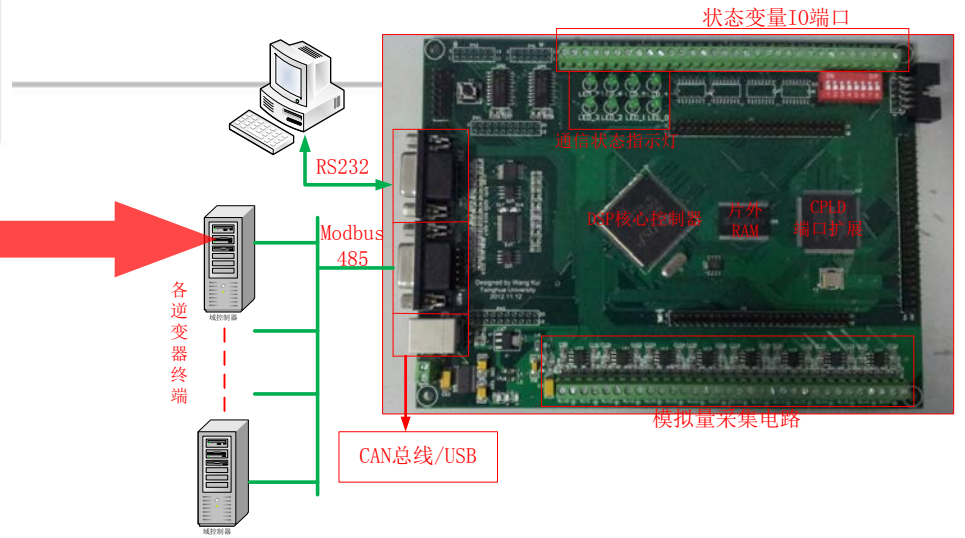
1. *Constant current*
2. *Constant power mode*

ESS is **lead-acid** battery, using
500 2V160AH lead-acid batteries 500V/320AH
battery group: 2 parallel of 250 series
Discharge depth is 65%
@50 kW inverter work about 2 hours @full capacity

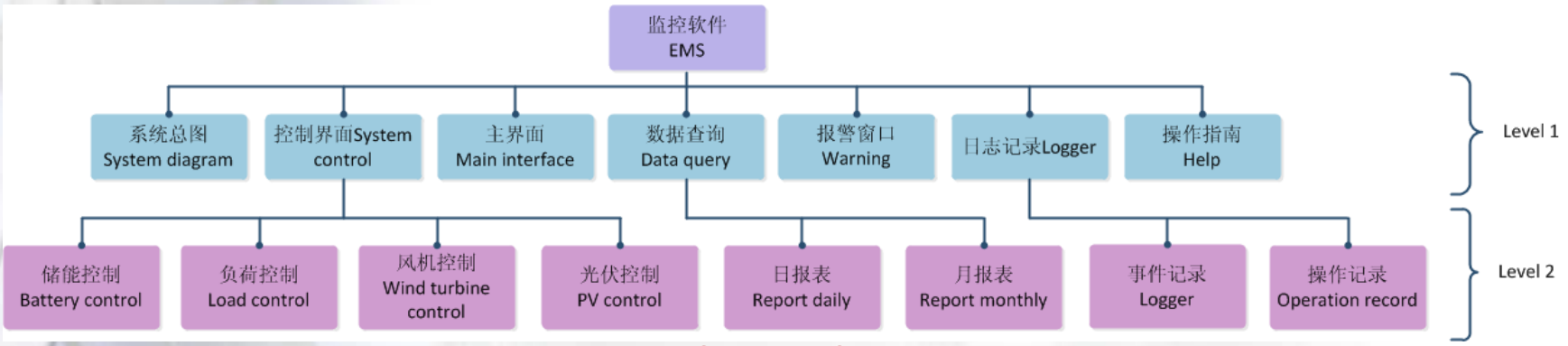
Energy Management System(EMS)



Energy management system



EMS Control board



The structure of EMS software

Smart grid in Denmark – The Omnia Project

MULTICAL®
Smart Meters for water

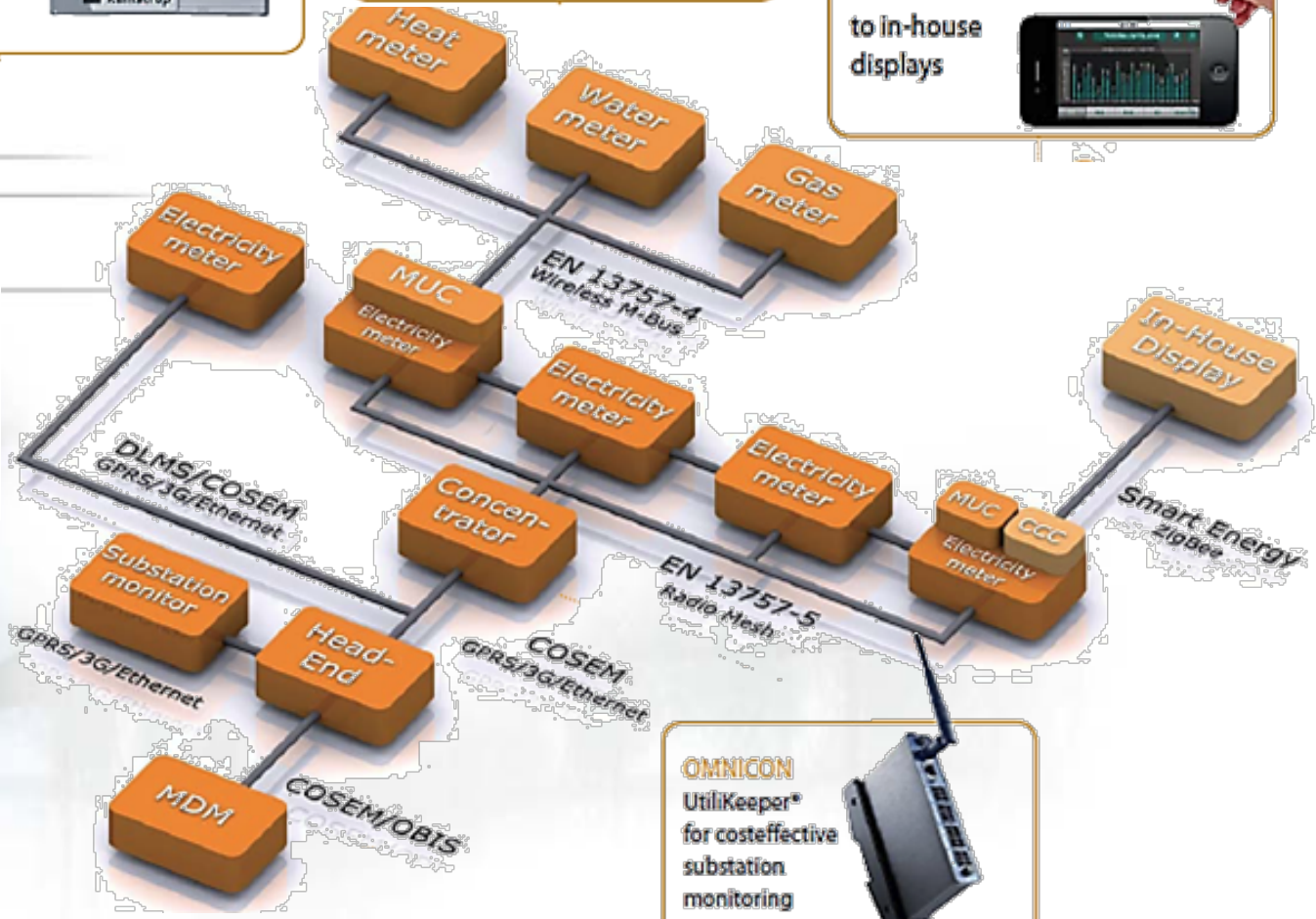
MULTICAL®
Smart meters for district heating

OMNIPOWER
Smart meters for electricity

OMNICON
Wireless communication to in-house displays

OMNISOFT
VisionAir software for data management and storage

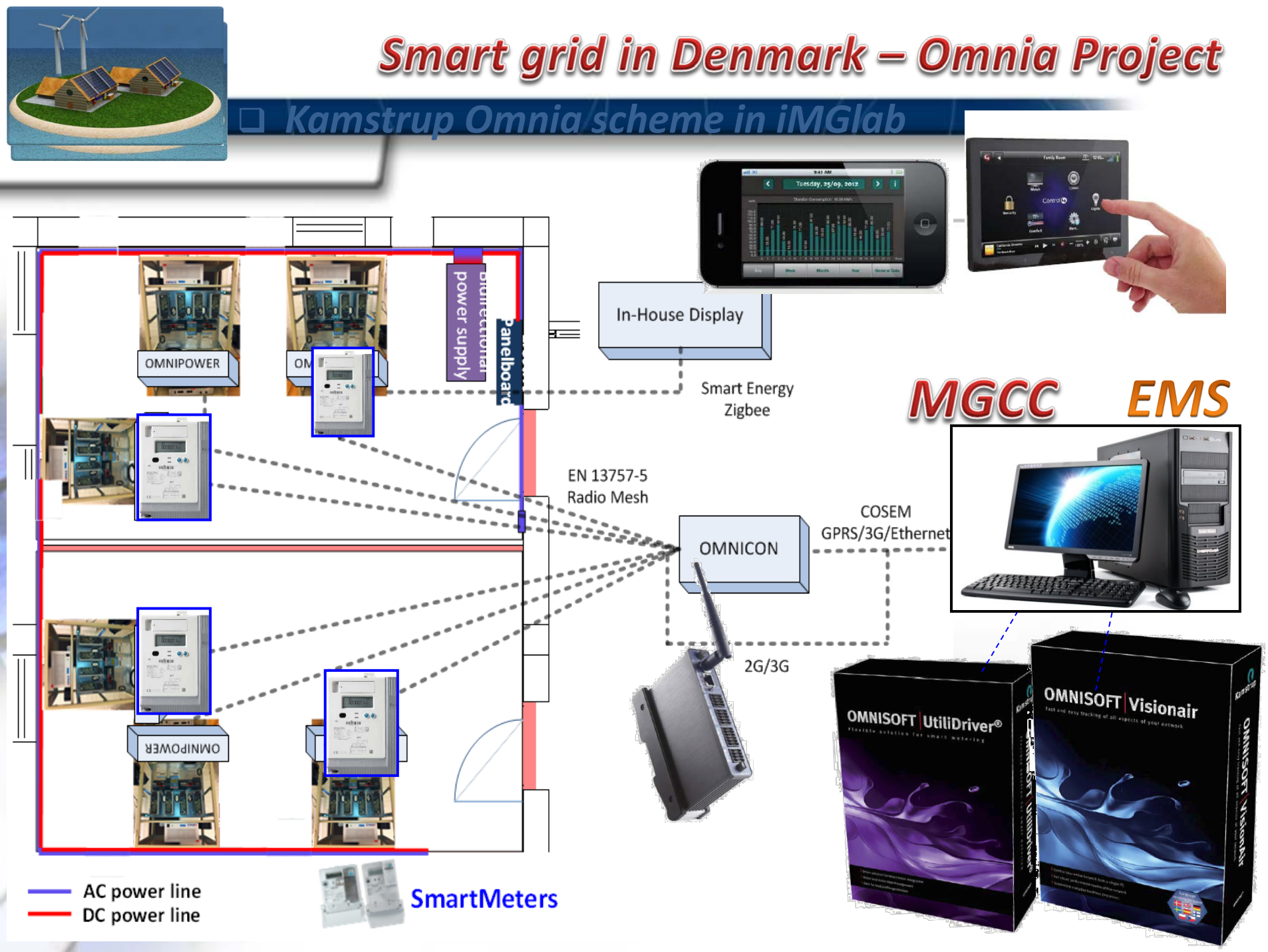
OMNICON
Data concentrator for communication infrastructure management



OMNICON
UtiliKeeper® for costeffective substation monitoring

Smart grid in Denmark – Omnia Project

❑ Kamstrup Omnia scheme in iMGlab



DSF Sino-Danish project 2014-2017

Intelligent DC Microgrid Living Lab

i-DClab

AALBORG UNIVERSITY
DENMARK

国家电网公司
STATE GRID
CORPORATION OF CHINA

The
Danish Council for
Strategic Research

Intelligent DC Microgrid Living Lab

- **Phase I: Design, modelling and control.**
- **Phase II: Coordination control** schemes between microgrid elements, including **communication** systems and **energy management systems** for DC microgrids.
- **Phase III:** Creation of **two Living Labs** as a user-centred research concept, to test innovation systems and elements that can conform a DC microgrid for different applications.

- **Home DC Microgrid Living Lab**, at AAU

to research and test DC distribution for **1-2 family houses**

- 工业微网设计 ***Industrial DC Microgrid Living Lab***,

At North China Electrical Power University (China), for research, demo and test of energy solutions for commercial buildings.

Intelligent DC Microgrid Living Lab

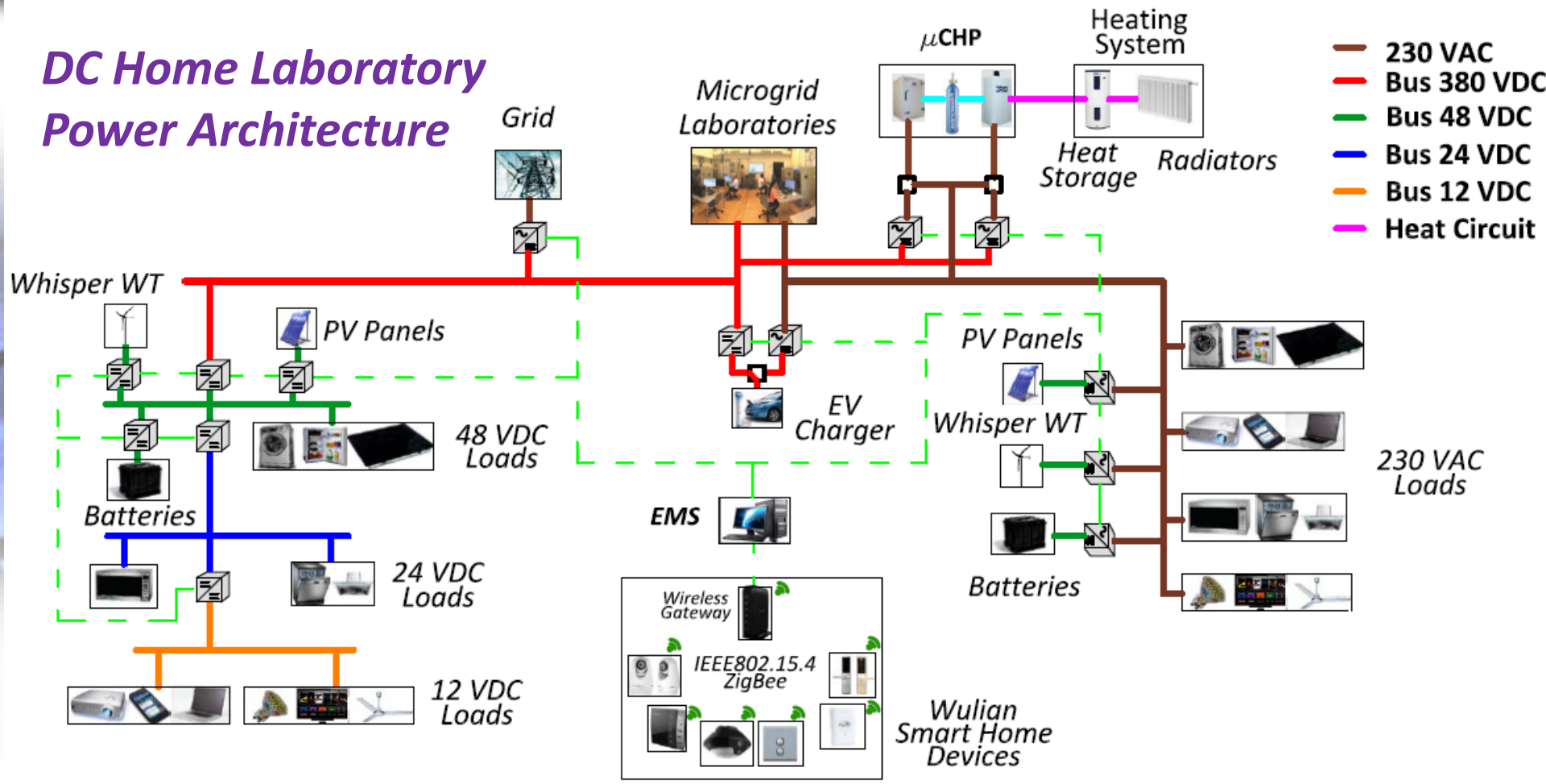
Demonstration of DC-home with Real DC appliances.

DC SIDE

1. 48 VDC Washing Machine
2. 24 VDC Microwave
3. 24 VDC Dish washer
4. 48 VDC Stove + Oven
5. 24 VDC Smoke Extractor
6. 48 VDC Fridge
7. 48 VDC Air Conditioner
8. 12 VDC Led Lights
9. 12 VDC Ceiling Fan
10. 12 VDC Projector
11. 12 VDC Mobile Charger
12. 12 VDC Laptop
13. Router Wifi
14. DVD Player
15. TV
16. Standing Led Light
17. 230 AC Power Plugs
18. 48 VDC PV Panels
19. 380 VDC EV Charger
20. 48 VDC Li-ion Batteries
21. Electric Vehicle

Intelligent DC Microgrid Living Lab

DC Home Laboratory Power Architecture



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

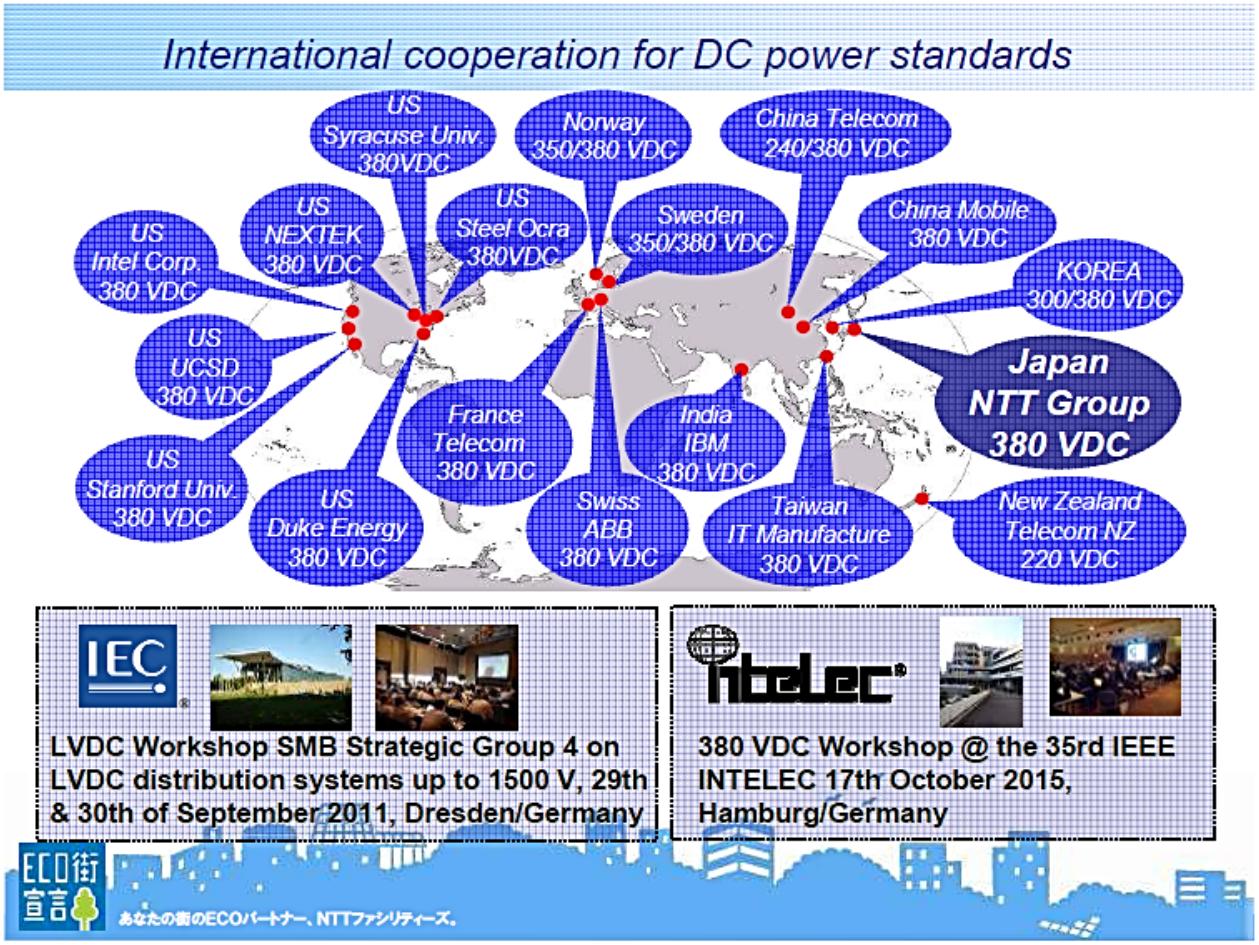
kk-electronic a/s

Kamstrup - metering solutions

NEOGRID TECHNOLOGIES

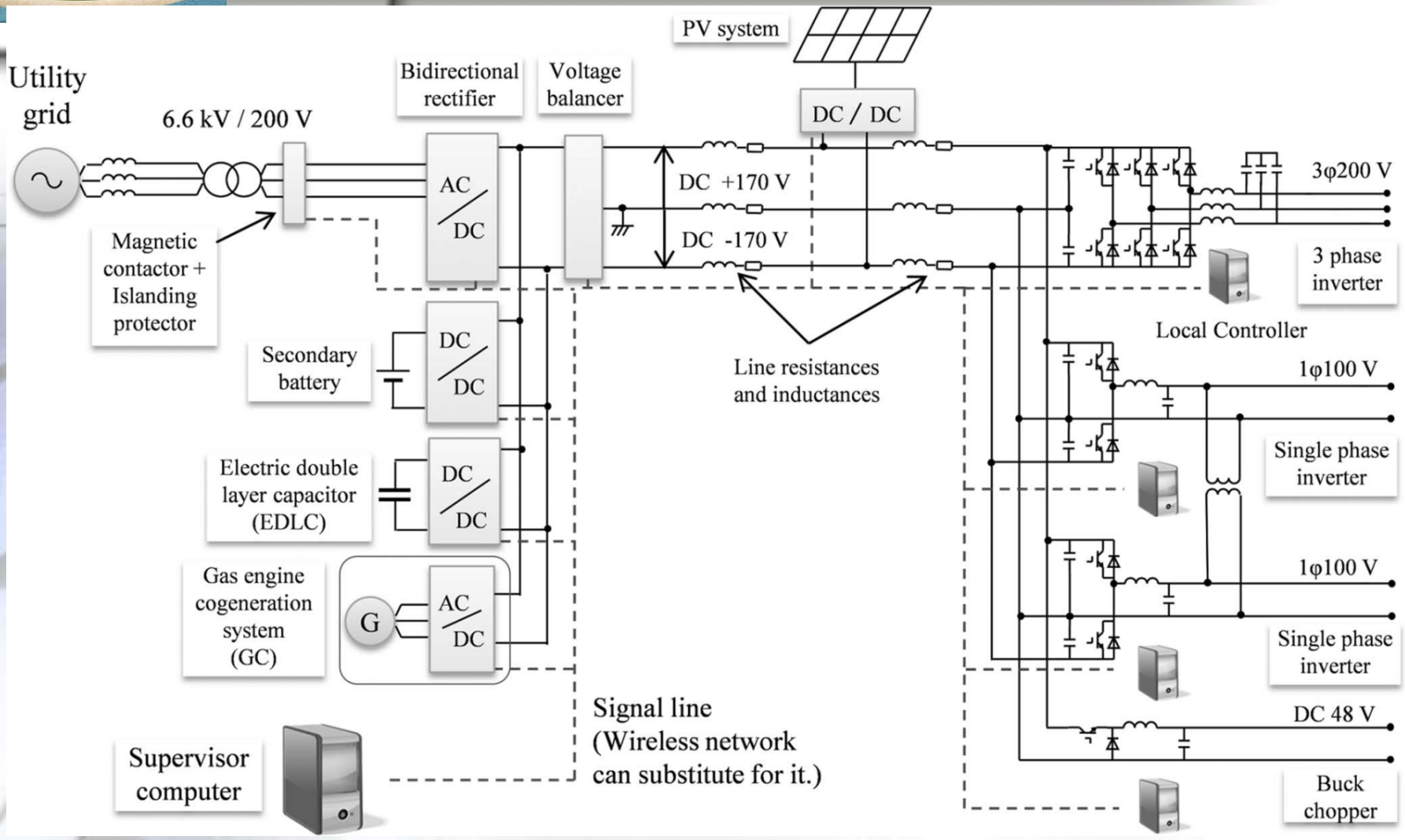
http://www.residentialvdc.et.aau.dk

Future Residential LVDC Power Distribution Architectures



http://www.residentialvdc.et.aau.dk

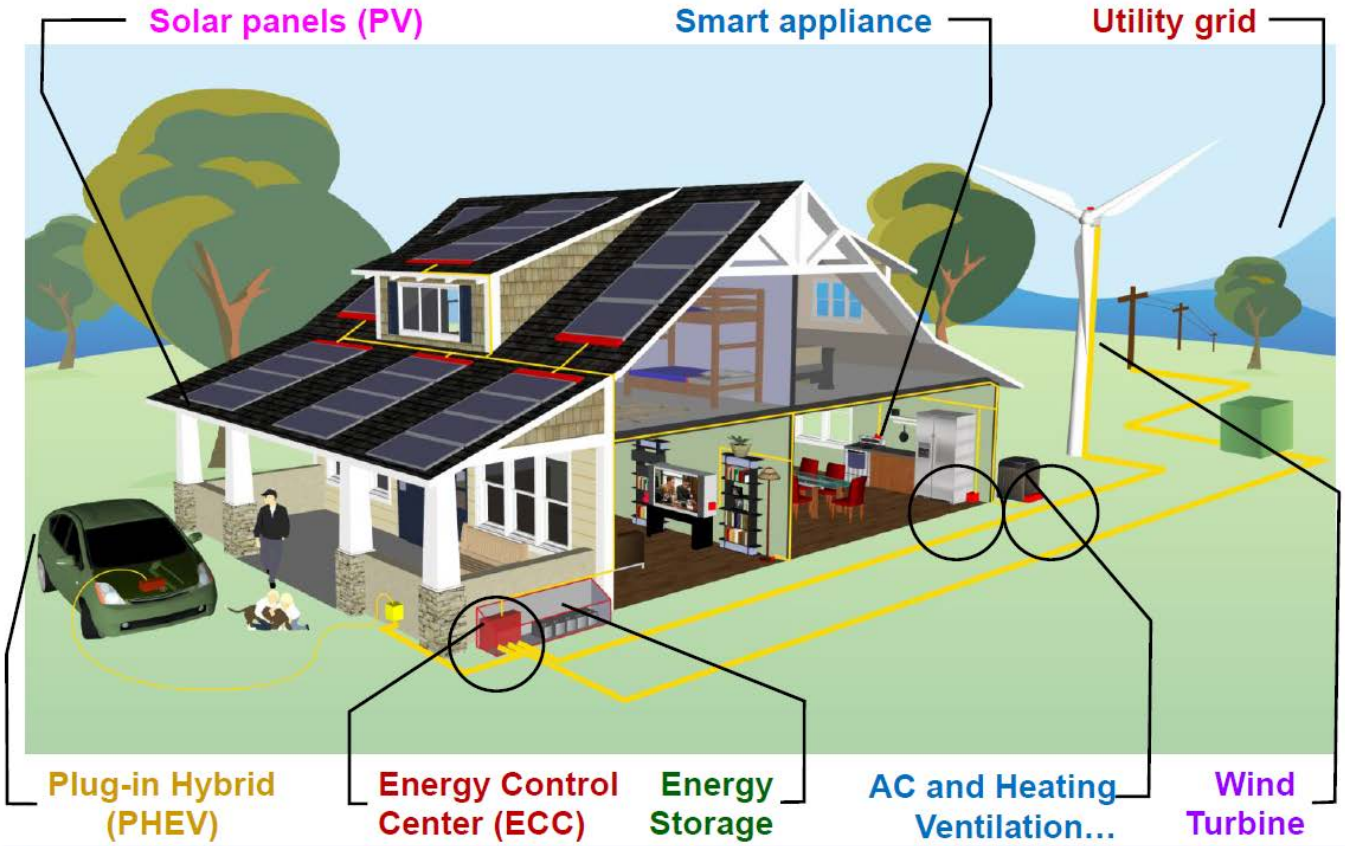
DC Homes: *Residential DC microgrid (Japan)*



http://www.residentialvdc.et.aau.dk

CPES: *Hybrid AC-DC NanoGrid System*

Future Energy Efficient Home/Building



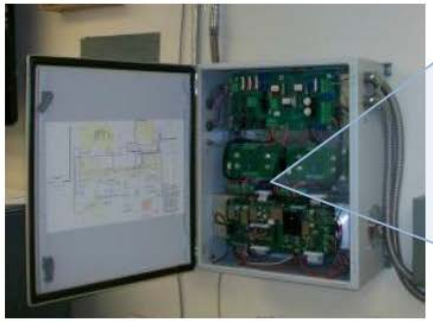
Different sources and loads are integrated with *power electronics converters*.

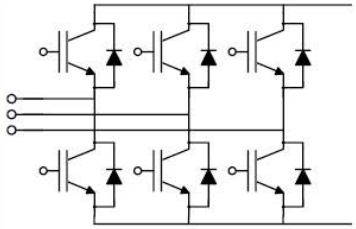
CPES: *Hybrid AC-DC NanoGrid System*

Wind Turbine System

Wind Turbine atop the Whittemore Hall

Converter installation in the CPES' lab



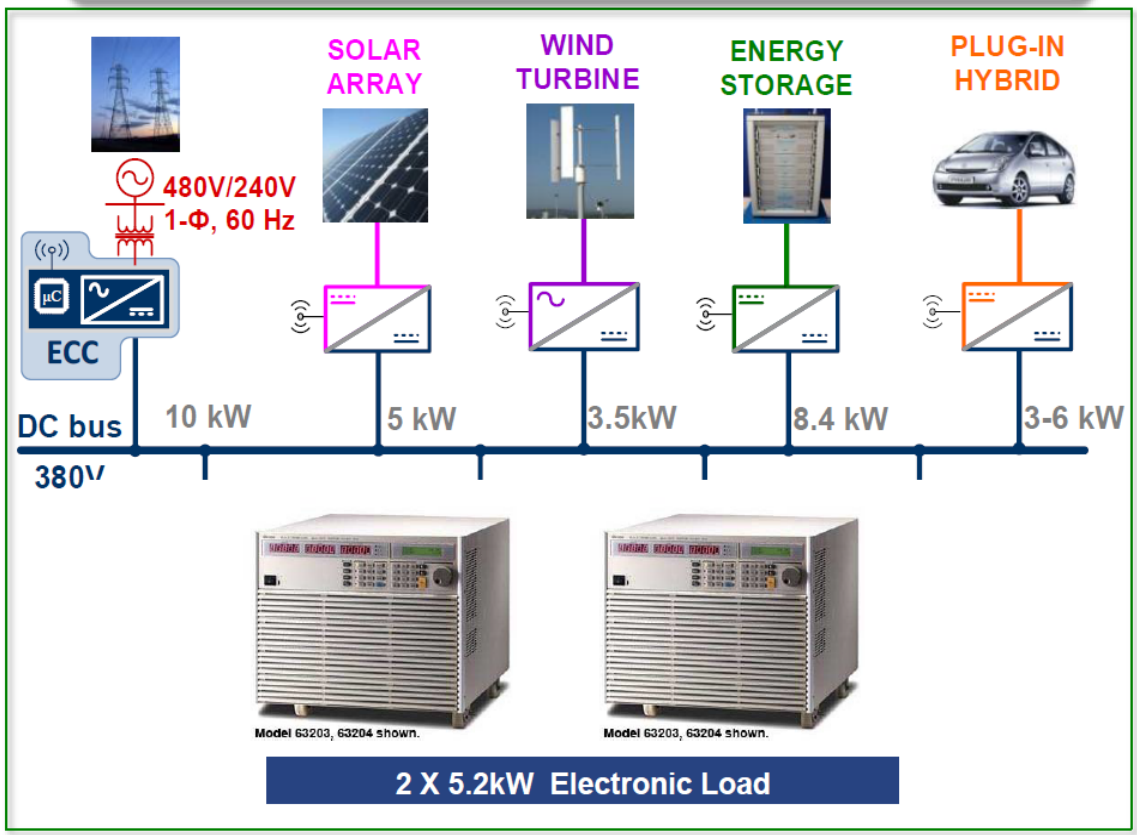


175 V, 5-15 Hz

Wind Turbine Dyno System

Minimized System for Validation

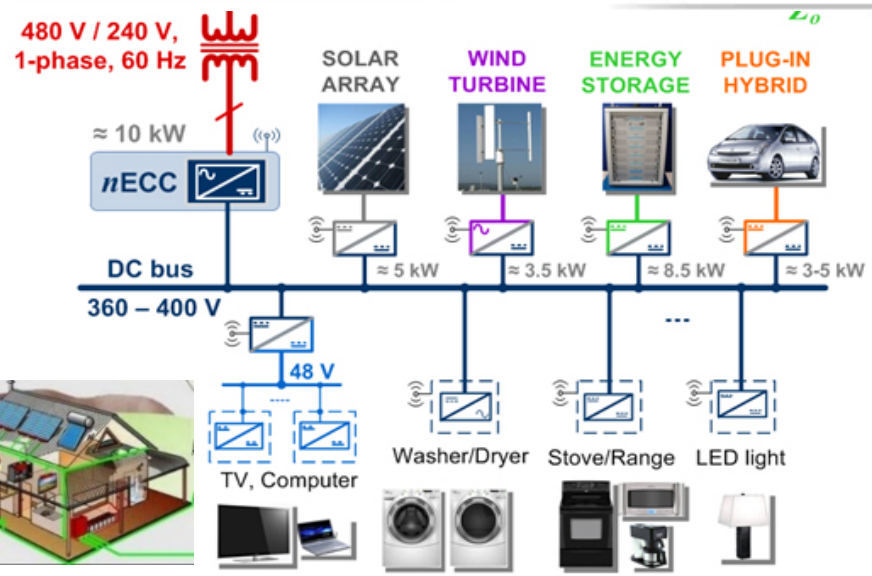
Minimized REN system (ECC, PV, Bat, Load)



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

4. Load demand

Renewable Energy and Nanogrids (REN)

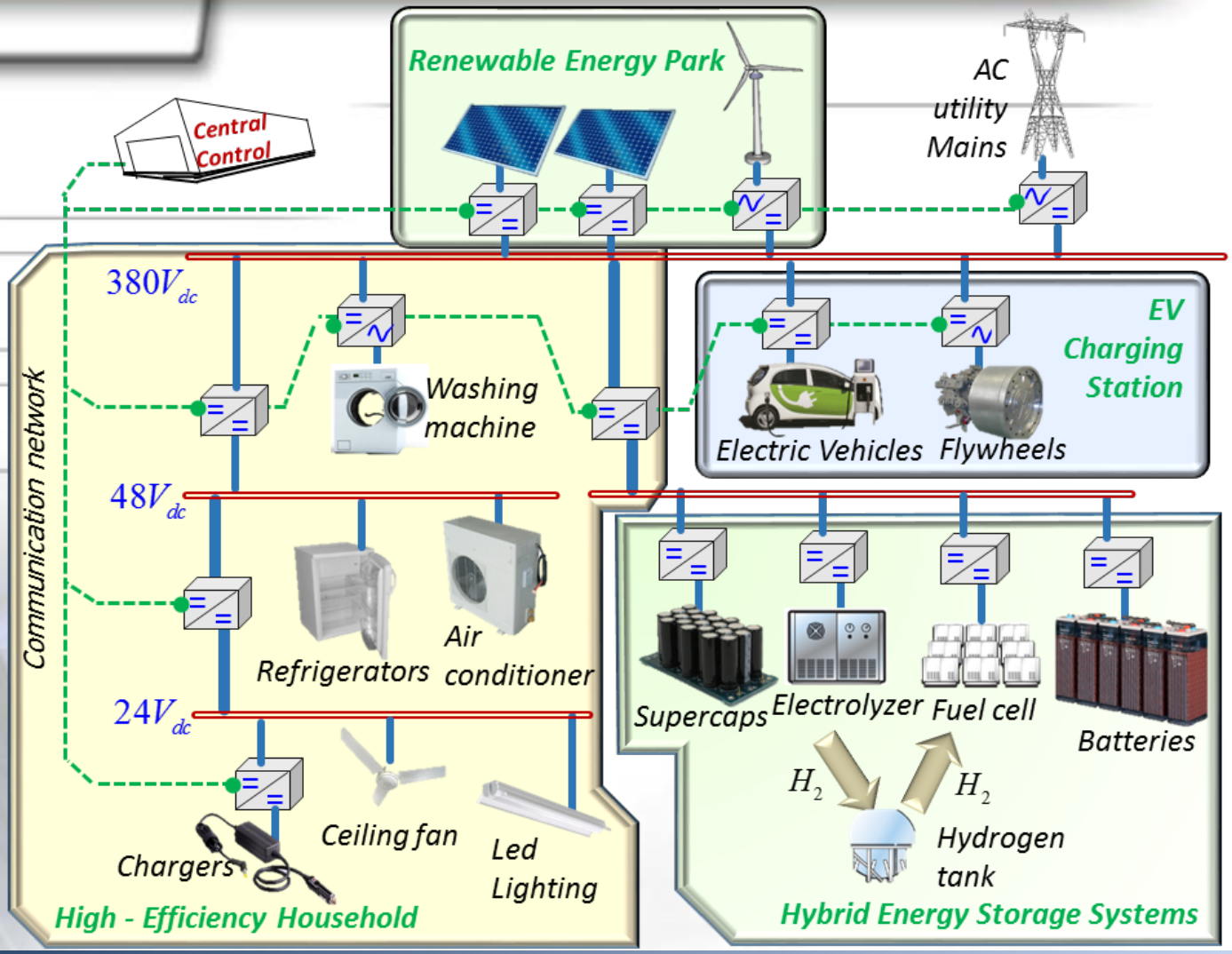


Work Scope

- *DC- and AC- nanogrid operation and performance*
- *Modular multi-level converters for nanogrids*
- *Power electronics applications for enhanced T&D grid performance and resource integration*

DELTA ABB HUAWEI GE CEI BOEING Agilent Technologies SIEMENS

Future Residential LVDC Power Distribution Architectures



http://www.residentialvdc.et.aau.dk

ERANET project 2014-2016

Flexible electric vehicle charging infrastructure Flex –ChEV

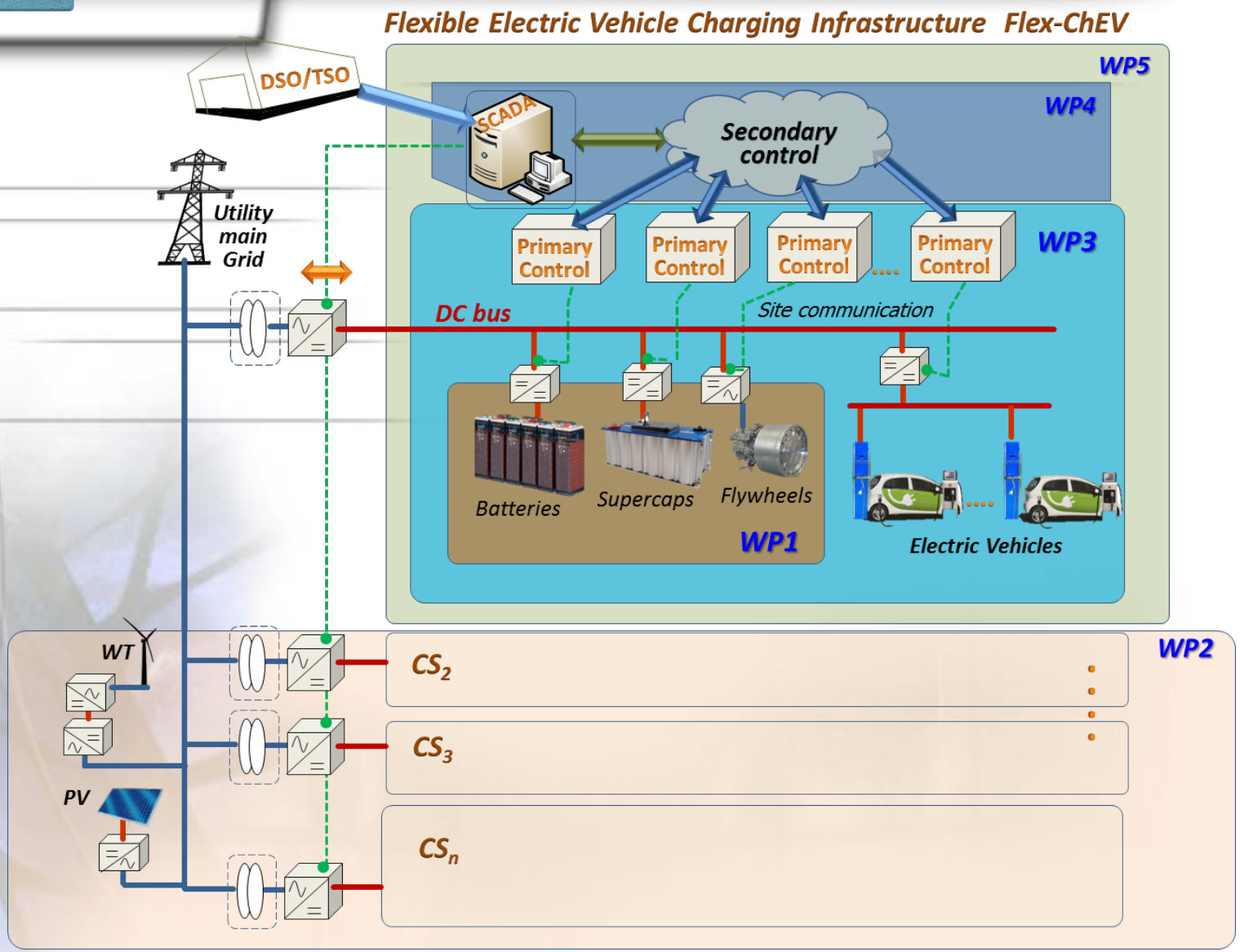
AALBORG UNIVERSITY
DENMARK

HØGSKOLEN
I NARVIK

UNIVERSITAS STUDIORUM ZAGRABIENSIS
MDCLXIX

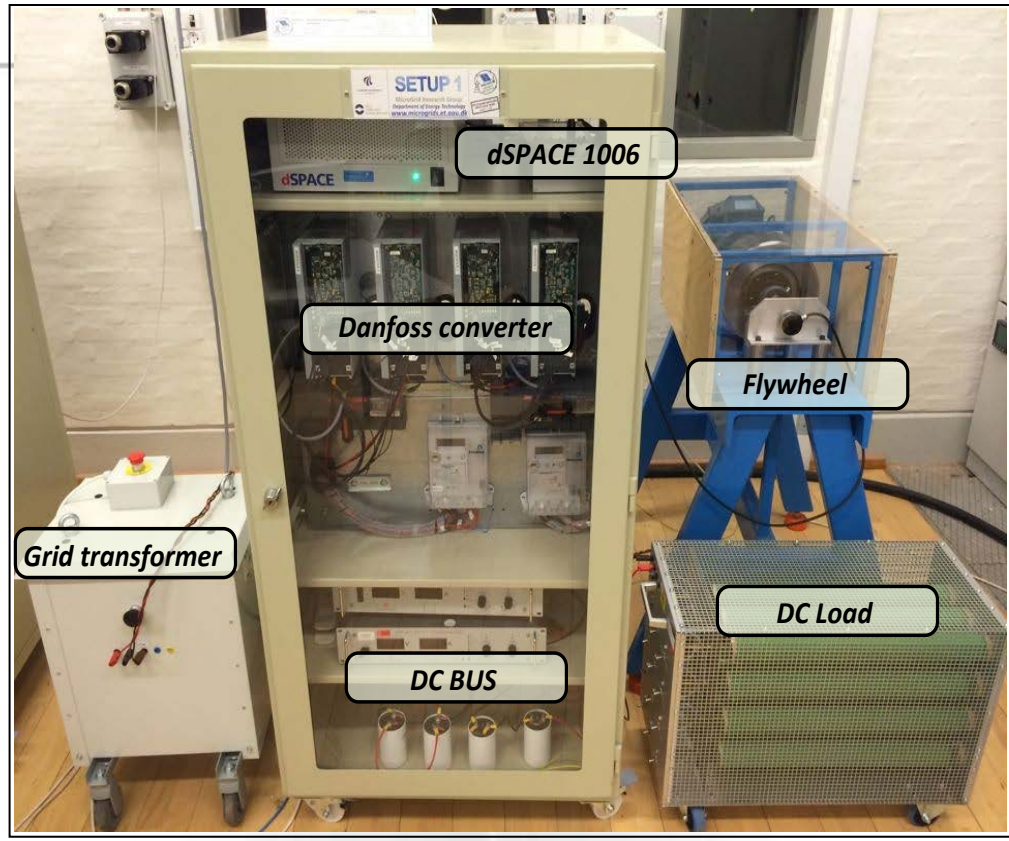
http://www.flexchev.et.aau.dk

Flexible electric vehicle charging infrastructure Flex –ChEV



Flexible electric vehicle charging infrastructure Flex –ChEV

- 2 year experience in 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



Research Challenges in MicroGrid technologies

juq@et.aau.dk
joz@et.aau.dk

MicroGrid RESEARCH PROGRAMME

Thank you for your attention!