RESEARCH CHALLENGES IN MICROGRID TECHNOLOGIES

MicroGrid
Research Programme leader and co-leader

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

Outline

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

Denmark

Površina	
Danska	42,894 km^2
Grenland	2,166,086 km^2
Farski otoci	1,399 km^2
Stanovništvo	5,580,413
Grenland	57,695
Farski otoci	49,483
Površina	
Hrvatska	56,594 km^2
Stanovništvo	4,290,612

- *Tečaj je danska kruna (1 DKK= 1.01 HRK)*
- *Razdoblje dnevnog svjetla varira od 7 sati zimi do 18 sati ljeti*
- *121 padalinskih dana u godini*
- *28% energije dolazi iz vjetroagregata*
- *Oko 80% stanovništva su protestanti*
- *Stopa nezaposlenosti je 7.7%*

GDP - Hrvatska	
Ukupno	$ 63,842 milijardi
Po stanovniku	$ 14,457
GDP - Danska	
Ukupno	$ 333,238 milijardi
Po stanovniku	$ 59,928

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 Techonolgy

- Electric Power Systems
- Power Electronic Systems
- **Electrical Machines**
- Fluid Power Mechatronic Systems
- Mechanics and Combustion
- Thermal Energy Systems

Multi-disciplinary Research Programmes

- Wind Turbine Systems
- Fluid Power in Wind and Wave Energy
- Biomass
- **Microgrids**
- Photovoltaic Systems
- Modern Power Transmission Systems
- Smart Grids and Active Networks
- Fuel Cell and Battery Systems
- Automotive and Industrial Drives

John K. Pedersen
Head of the Institute of Energy Technology, Aalborg University.

- ***Approximately 40 faculty members***
- ***Approximately 70 PhD students***
- ***Approximately 250 students***
- ***Approximately 20 TAPs (technical administrative employees)***
- ***Approximately 50% of the turnover comes from external projects***

MicroGrid Research Programme

Programme Purpose

MicroGrid Research Programme **Areas**

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

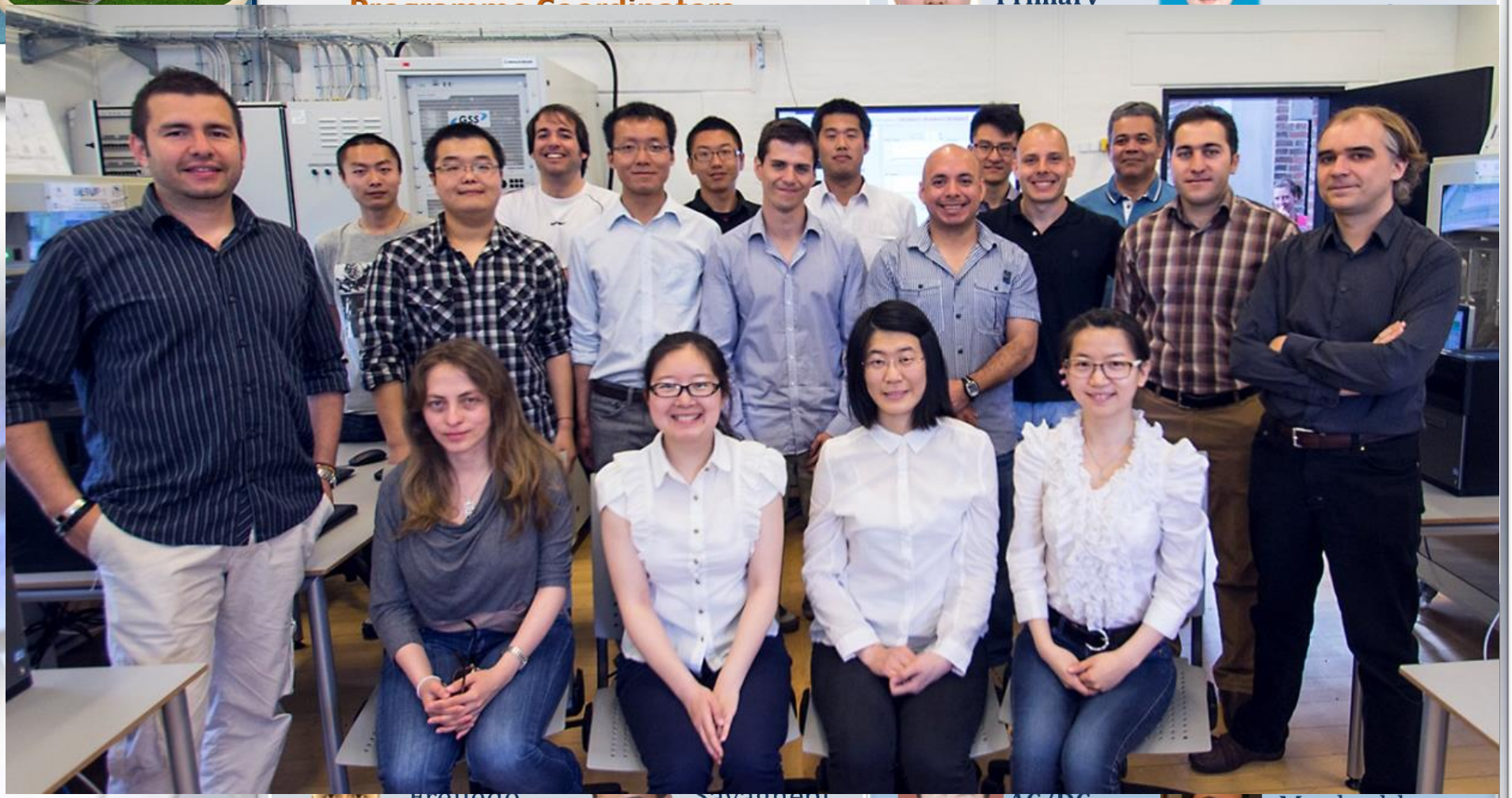
- ✓ Modeling
- ✓ Control & Operation
- ✓ Energy Storage
- ✓ Protection
- ✓ Power Quality
- ✓ Standard-based ICT
- ✓ Networked Control
- ✓ EMS & Optimization
- ✓ Multi-Agents

MICROGRID RESEARCH TEAM

PhDs

Dan Wu
Primary

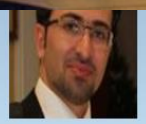
Yajuan Guan
Ancillary



Freijedo
Modelling and Control in MGs

Savaghebi
Power Quality in MGs

AC/DC Hybrid MG



Moghaddam
EMS

PhD Guests

ZANIMLJIVI PODACI

Faculty of Engineering and Science **–** organiziran u 12 zavoda koji obuhvaćaju razne klasične (matematika, kemija, fizika,strojarstvo) i moderne disciplne (nanotehnologije, energetske tehnologije). Fakultet je najveći od svih koji djeluju u skloupu sveučilišta i broji oko 5000 studenata i 1800 zaposlenika.

Najistaknutije smjernice istraživanja:

- Obnovljivi izvori energije: Većina istraživanja sa odvija u sklopu zavoda za energetske tehnologije, ***Department of Energy Technology (http://www.et.aau.dk).***
- ICT: Sveučilište uzlaže značajna sredstva u razvoj ICT sektora zbog jednostavnog transfera predloženih rješenja iz akademije u industriju. ***Department of Computer Science (http://www.cs.aau.dk/)*** i ***Department of Electronic Systems (http://www.es.aau.dk/).***

Primanja zaposlenka (bruto u DKK):

- Redoviti profesori: 51,513,17 + 8,689.43
- Izvanredni profesori: 34,359.42 + 8,689.43
- Docenti: 34,359.42 + 4,873.60
- Post-Doc: od 28,197.67 do 32,389.33 + 4,873.60
- PhD student: 28,197.67 + 1,257.86

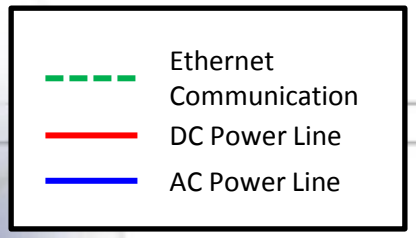
** Akademska zvanja u Danskoj nisu trajna, maksimanlno trajanje ugovora je 6 godina. Dva puta godišnje svaki je zaposlenik dužan podnijeti izvještaj o rezultatima svoga rada.*

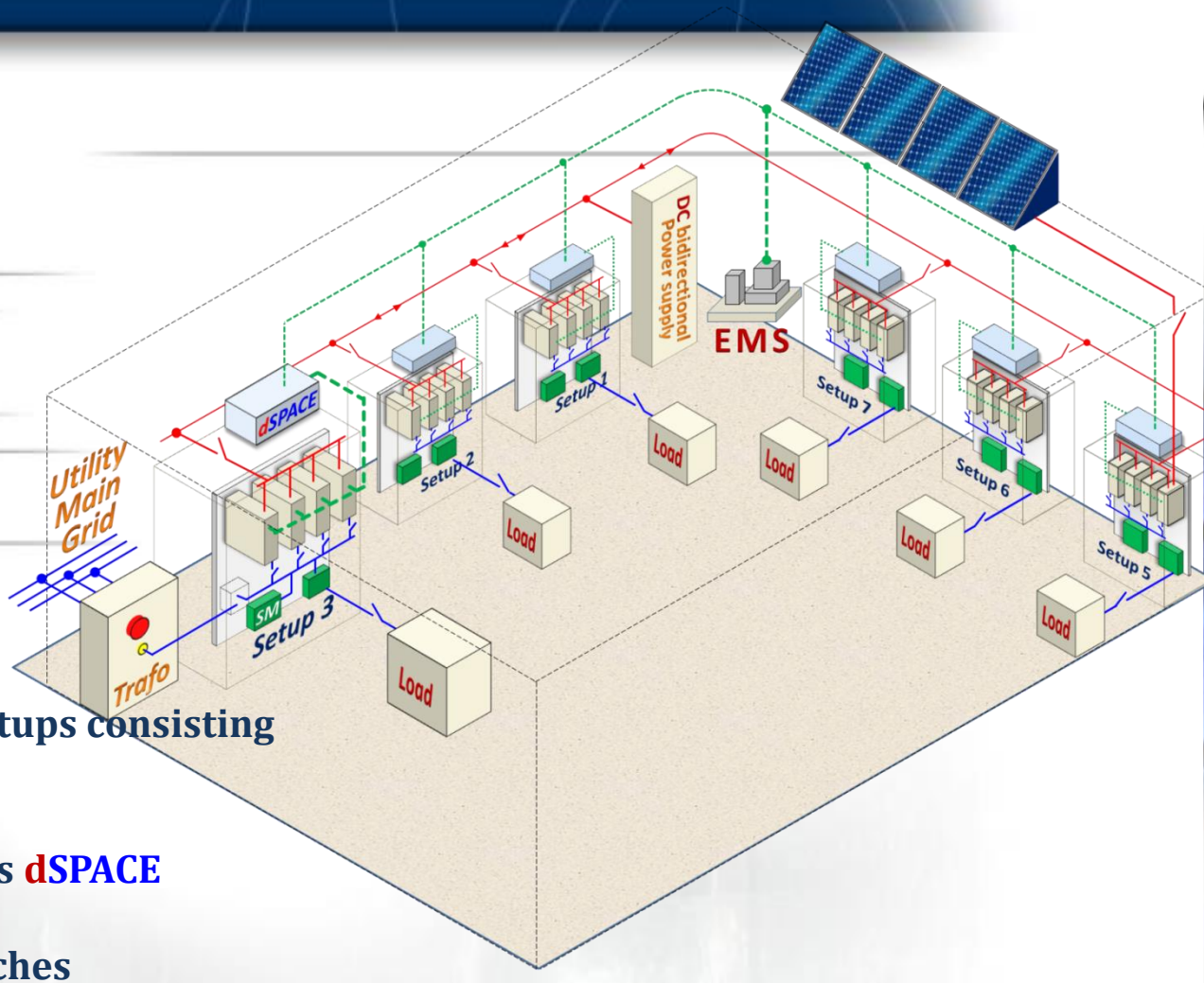
ET Intelligent MicroGrid Laboratory

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

ET Intelligent MicroGrid Laboratory

AAU Intelligent MicroGrid Laboratory

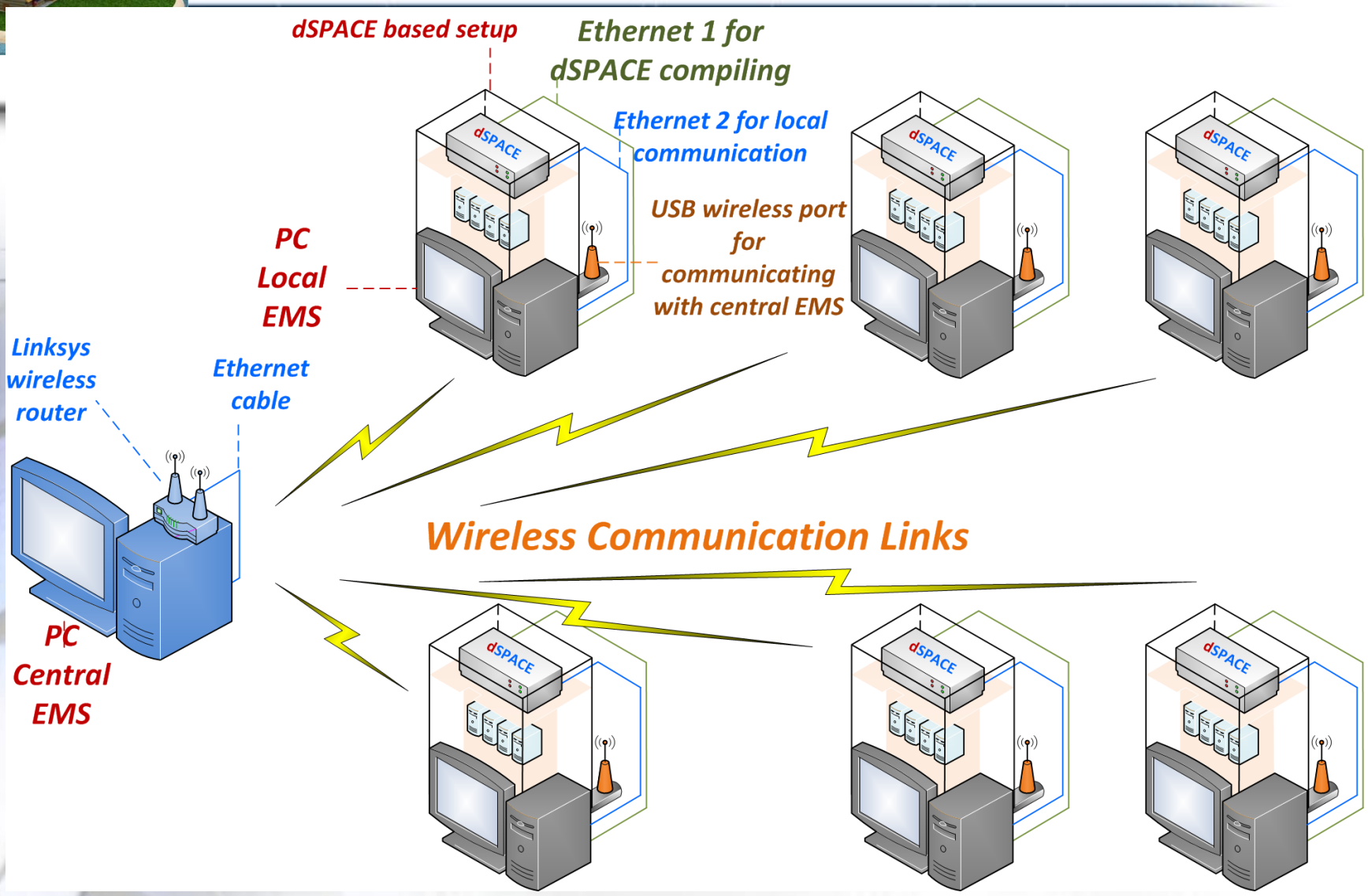




The laboratory is based on 6 Setups consisting of:

- **24 DC-AC converters**
- **6 real-time control platforms dSPACE**
- **L-C-L filters**
- **Motorized change-over switches**
- **Smart-meters.**

ET Intelligent MicroGrid Laboratory



Microgrid Central Controller – EMS in labview

NewVersion0518.vi

LAB OVERVIEW | MG Platform 1 | MG Platform 2 | MG Platform 3 | MG Platform 4 | MG Platform 5 | MG Platform 6 | MG Platform 7

007 *Islanded MG Unbalance Comp.*

PCC Voltage 7

DC link Voltage 7

Grid

Unbalanced Load 1 7

Load 2 7

PCC

LCL LCL LCL LCL

Vdc 656.41 V

Inverter 1 Inverter 2 Inverter 3 Inverter 4

dSPACE

System Status

Protection

Voltage Unbalance Information

VpccNd_chart — VpccNd -1.01 V

VpccNq_chart — VpccNq 0.52 V

VUF_chart — VUFpcc 0.25 %

Vpcc_chart — Vpcc 223.04 Vrms

Unbalance Compensation Secondary Control

Comp. Activation — Play

reset comp. ctrl

UFref 0.25

LoopStep 1

PID gains

proportional gain (Kc) 0.500

integral time (Ti, min) 0.001

derivative time (Td, min) 0.000

VUF on PCC 0.25 %

Reference Value 0.25 %

Input and setpoint

NATIONAL INSTRUMENTS LabVIEW Student Edition

Main Application Instance

Smart grid in Denmark – The Omnia Project

MULTICAL®
Smart Meters
for water

MULTICAL®
Smart
meters
for district
heating

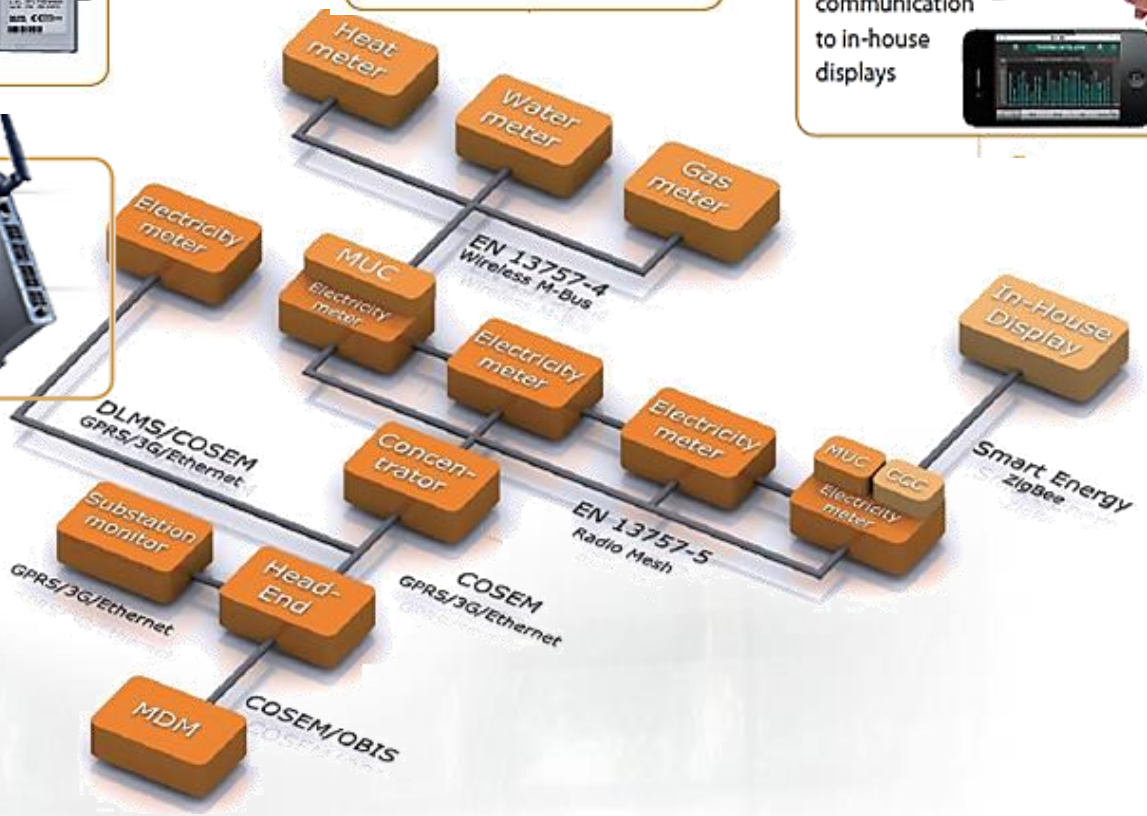
OMNIPOWER
Smart meters
for electricity

OMNICON
Wireless
communication
to in-house
displays

OMNISOFT
VisionAir
software for data
management
and storage

OMNICON
UtiliKeeper®
for costeffective
substation
monitoring

OMNICON
Data concentrator
for communication
infrastructure
management



Smart grid in Denmark – Omnia Project

❑ Kamstrup Omnia scheme in iMGlab

In-House Display

Smart Energy
Zigbee

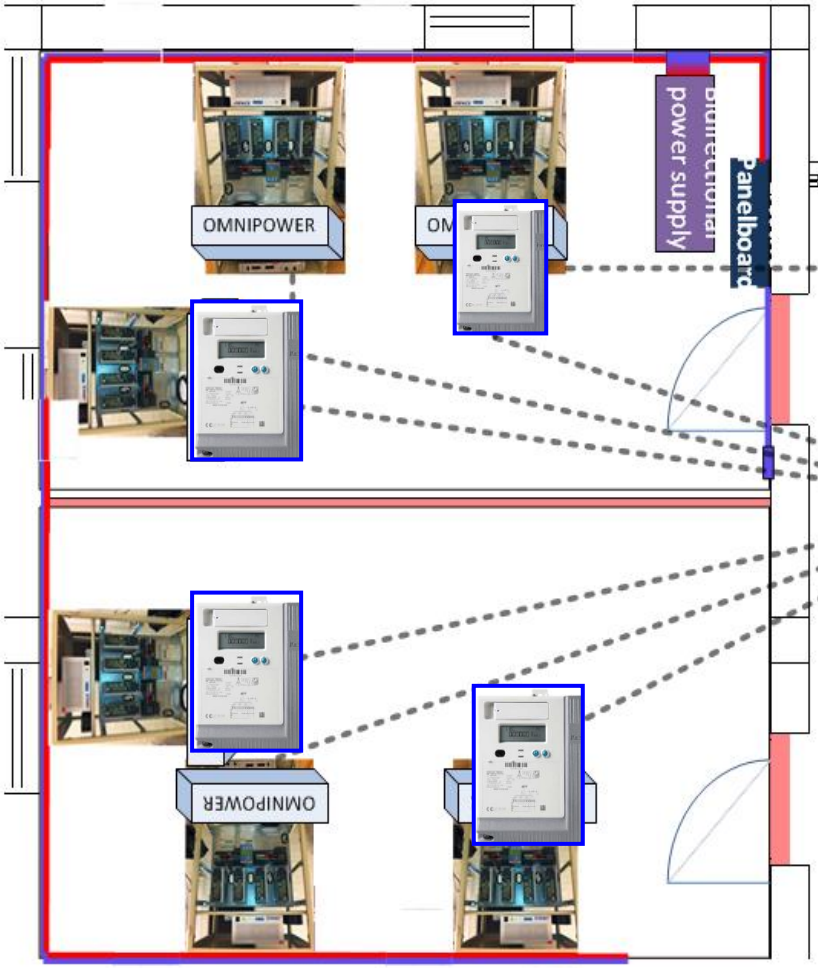
MGCC EMS

EN 13757-5
Radio Mesh

COSEM
GPRS/3G/Ethernet

OMNICON

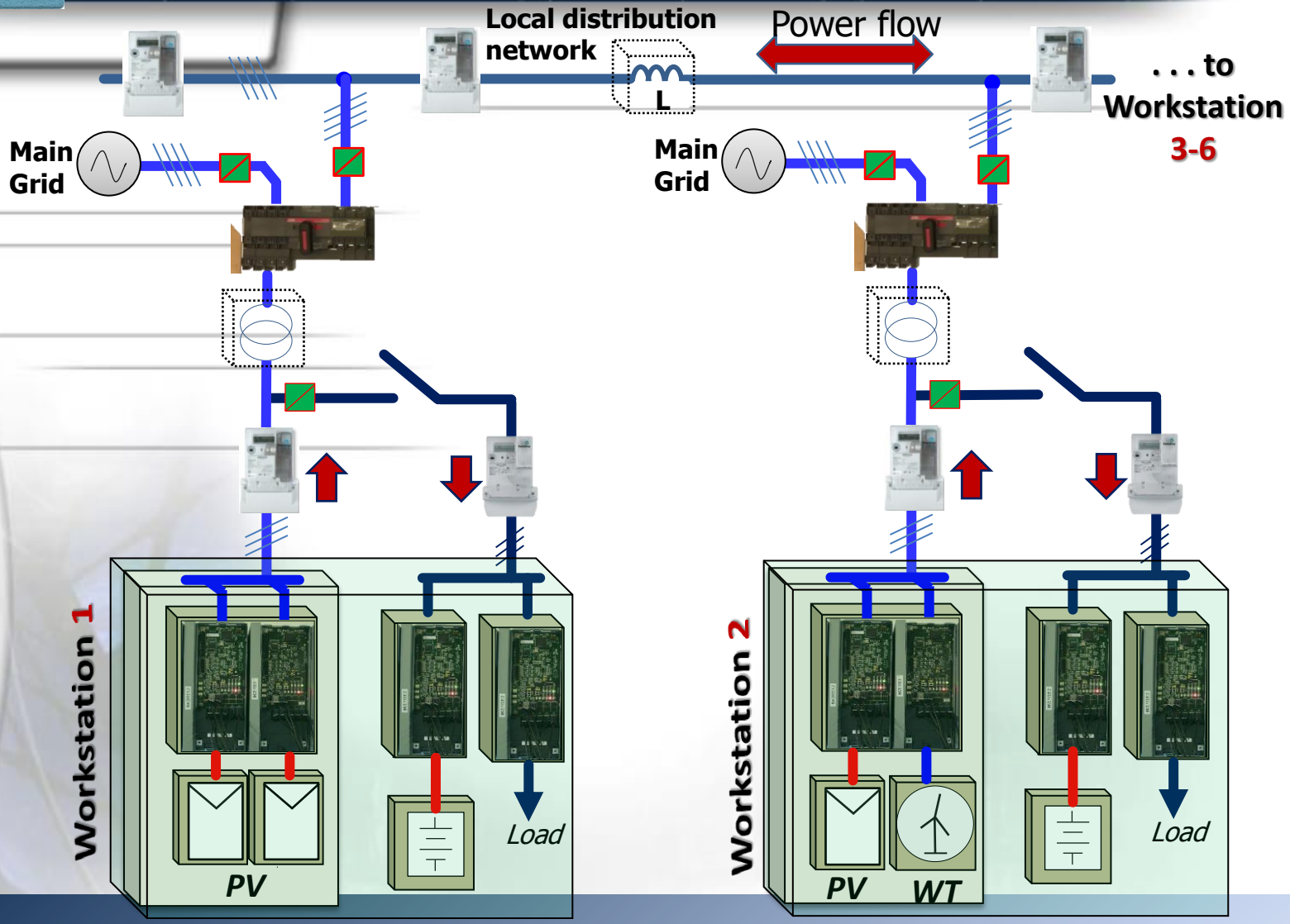
2G/3G



AC power line
DC power line

SmartMeters

Case Study DES-ET AAU



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

AC MG COURSE Fall 2012

Distributed Secondary Control of an Islanded MicroGrid

Inverter 1 + Inverter 2 + Load

AALBORG UNIVERSITY

Active Power Control: 0.00080 | 0.00080

Reactive Power Control: 0.1600 | 0.1600

m1, m2, n1, n2

Start Synch. | Stop Synch.

Synchronization Process

System Measurements: V1 RMS (V) 323.67 | I1 RMS (A) ---- | Vdc (V) 647.28 | V2 RMS (V) 323.67 | I2 RMS (I) 323.67 | Freq. (Hz) 49.97

Inverter 1: Start | Stop | RST HW TRIP

Inverter 2: Start | Stop | RST HW TRIP

Frequency Restoration for both DGs

DELTA F1 0.00 | DELTA F2 -0.00 | DELTA E1 -1.19 | DELTA E2 1.20

Amplitude Restoration for both DGs

Start Droop 1 | Start Droop 2

Droop Voltage Reference (E)

Active power for both DGs

DeltaP (VAr) 0.35 | DeltaQ (VAr) 0.52

Reactive power for both DGs

Voltage and Frequency Deviations: E1d | E2d | F1 | F2

Distributed Secondary Control: Start | Stop

Secondary Control (Frequency)		Secondary Control (Voltage Amplitude)		Secondary Control (Reactive Power)	Communication Delay
0.00050	2.0000	0.00050	1.0000	0.1500	0.000

Kpf, KpE, KiQ, Delay, Kif, KiE

PPC - threephgpi - MainData | Start | Settings... | 100 % | Length 20 | Auto Repeat | Downsampling 5 | Trigger Signal | On/Off | Level 0 | Delay 0 | Select trigger signal: VR1 | VR2 | VgR

MicroGrids Courses

AC Microgrids

Industrial/PhD course on
AC Microgrids
in Theory and Practice

Industrial/Ph.D. Course in

AC Microgrids

– in theory and practice

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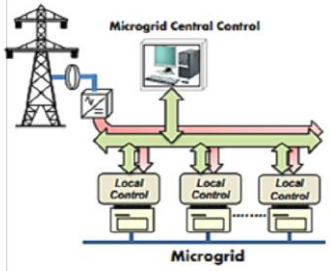
DENMARK

Department of Energy Technology
Aalborg, Denmark



DC Microgrids

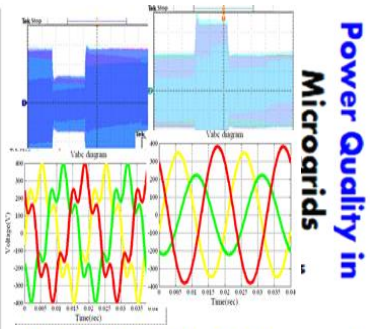
Industrial/Ph.D. Course in

DC Microgrids

- in Theory and Practice

AALBORG UNIVERSITY
DENMARK

Department of Energy Technology
Aalborg, Denmark



Power Quality in Microgrids

Industrial/Ph.D. Course in

Power Quality in MicroGrids

– in theory and practice

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DENMARK

Department of Energy Technology
Aalborg, Denmark

Industrial/Ph.D. Course in

EMS and Optimization

- In Theory and Practice

AALBORG UNIVERSITY
DENMARK

Department of Energy Technology
Aalborg, Denmark

Microgrid research and activities

www.microgrids.et.aau.dk

AALBORG UNIVERSITY

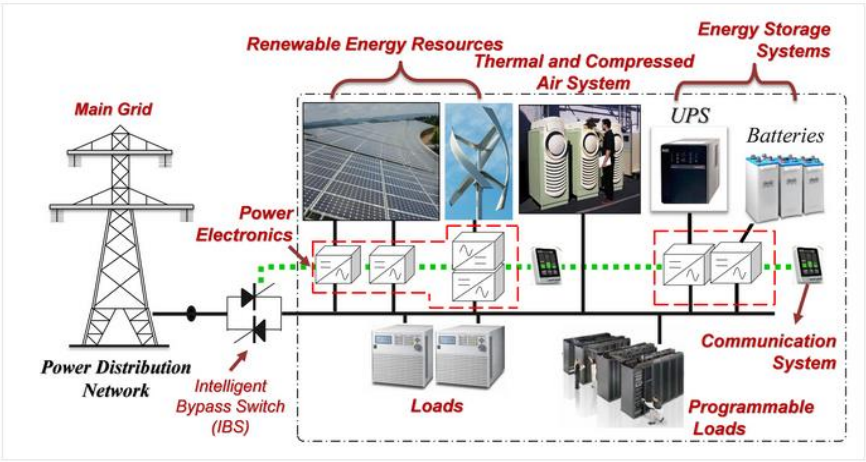
Persons Websites

Search

ALL PROG. | INTRO | MISSION | FOCUS AREAS | ACTIVITIES | PUBLICATIONS | LAB. FACILITIES

Introduction on 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.



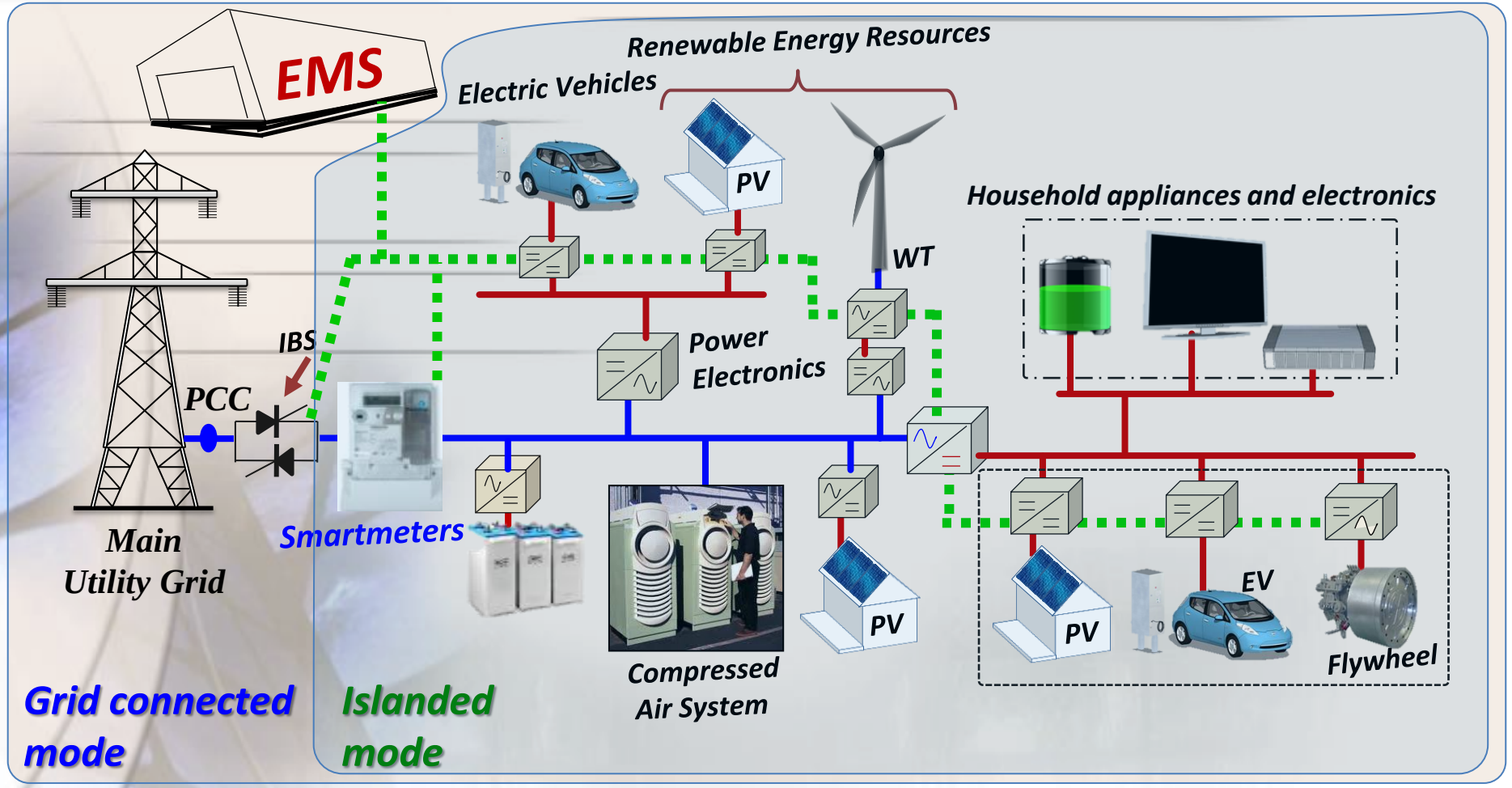
The MicroGrid research programme areas include AC and DC MicroGrids control and management, centralized and distributed control architectures, power quality and protections, multi agent systems, standard-based information and communication technologies, online optimization techniques and energy management systems. All of the foregoing can be also conceived within a problem based learning (PBL) education for Master, PhD students, and Industrial partners.
The MicroGrid research programme is connected to other multidisciplinary programmes of the Energy Technology and the Electronic Systems departments of Aalborg University. The program also promotes national and international cooperation with universities, institutions and companies.

- HOME
- THE DEPARTMENT
- RESEARCH PROGRAMMES
  - AUTOMOTIVE AND INDUSTRIAL DRIVES
  - BIOMASS
  - EFFICIENT AND RELIABLE POWER ELECTRONICS
  - FLUID POWER IN WIND AND WAVE ENERGY
  - FUEL CELL AND BATTERY SYSTEMS
  - GREEN BUILDINGS
  - MICROGRIDS
  - MODERN POWER TRANSMISSION SYSTEMS
  - PHOTOVOLTAIC SYSTEMS
  - SMART GRIDS AND ACTIVE NETWORKS
  - THERMOELECTRICS
  - WIND POWER SYSTEMS
- PUBLICATIONS
- PHD
- EDUCATION
- ENERGY SPONSOR PROGRAMME
- INTERNATIONAL RELATIONS
- VACANCIES, SCHOLARSHIPS AND

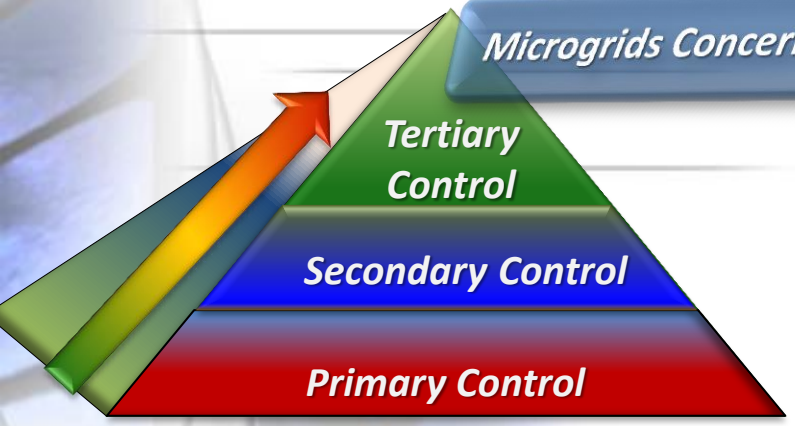
Outline

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

The concept of Microgrids

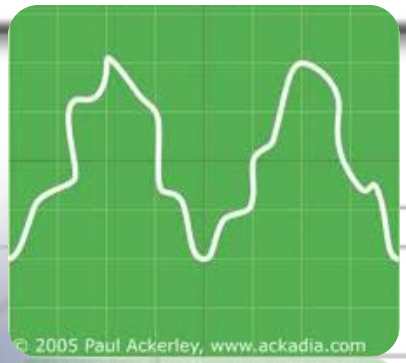


Hierarchical Control for MicroGrids



- Microgrids Concerns...
  - Power Quality enhancement
    - P/Q flow Control
  - Islanding capability and independence
  - Energy cost saving and high efficiency
  - System recovery under faults (selfheal)

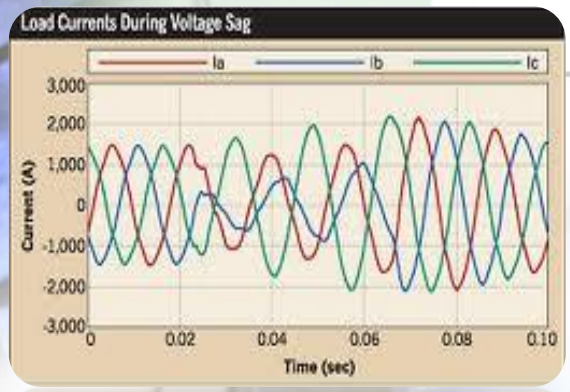
Issues in MicroGrids: *Power Quality*



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.***

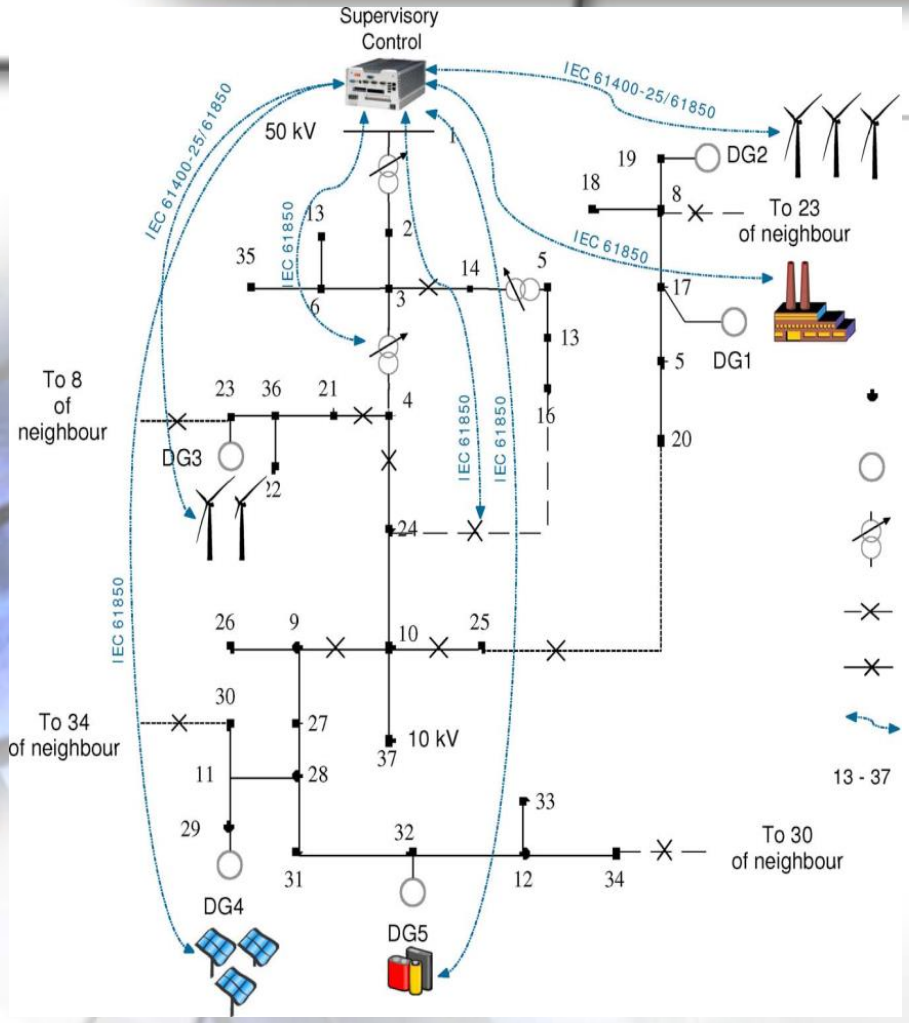
How to Coordinate harmonic/unbalance compensation?

The Whac-a-mole effect

Primary control
Harmonic virtual impedance

Secondary control
Harmonic/unbalance coordination control

Issues in MicroGrids: *Communications*



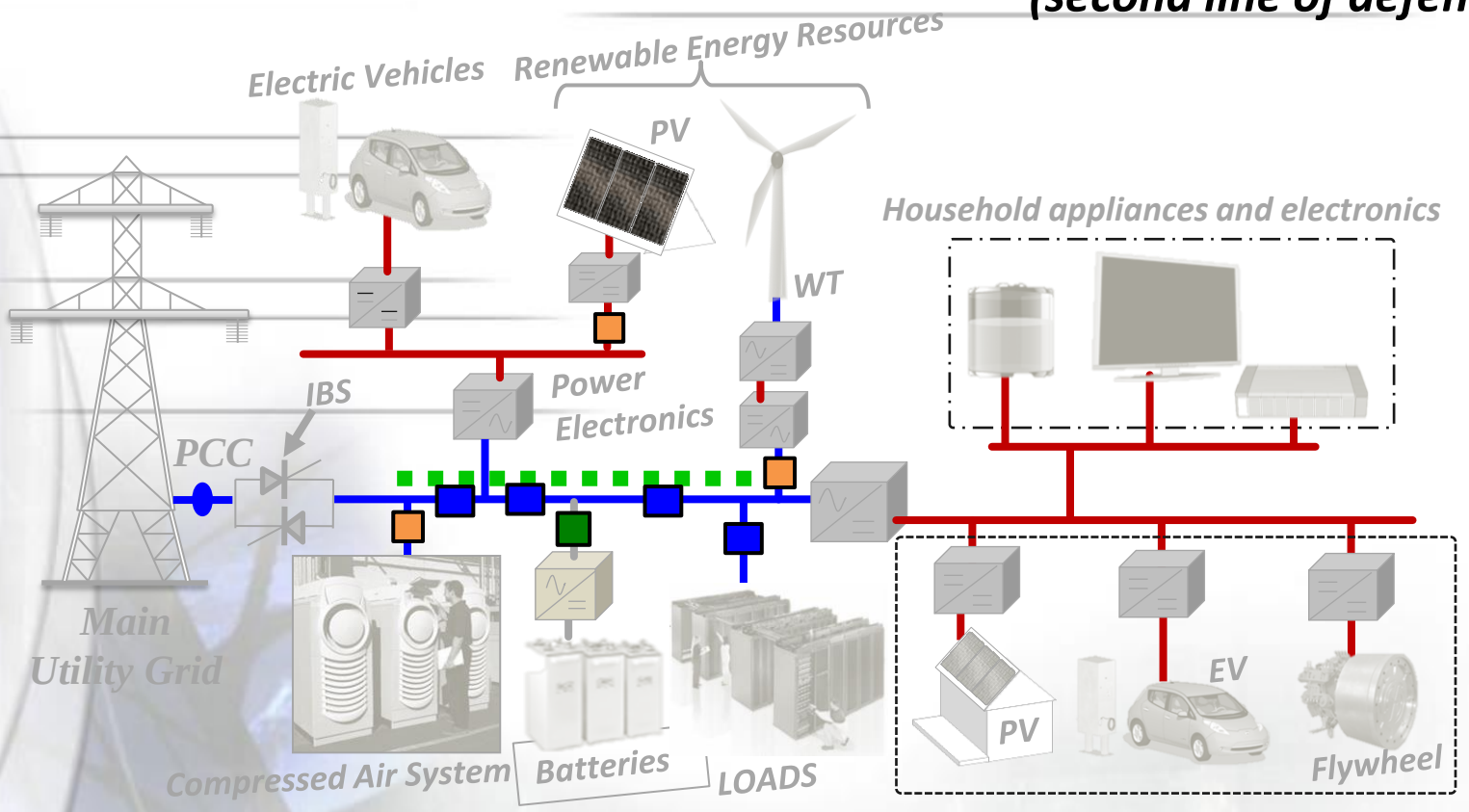
Communication model provided by ***IEC 61850 & IEC 61400-25*** to describe the physical devices in the network model.

- 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)



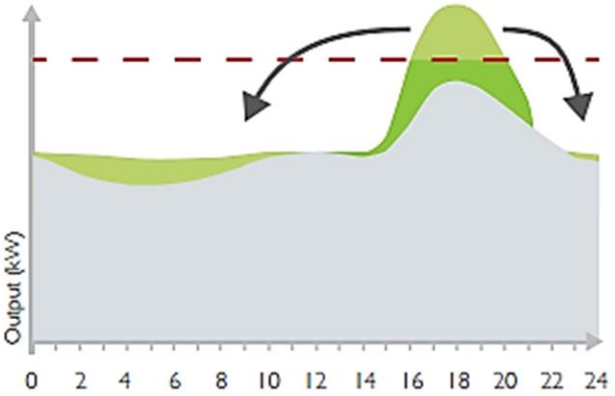
Source Protection ***Network Protection*** ***Bidirectional Protection***

Shifting the energy paradigm

Smart Grid Strategy

Danish Ministry of Climate, Energy and Building

May 2013



Energy Sector

- **50% consumers remotely read hourly meters** — 2013
- **Model for hourly settle and variable tariffs** — 2014
- *Wholesale and retail markets ready to manage* ***flexible electricity consumption*** — 2015 2016 2017 2018 2019 2020

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 technologies applications in Denmark

Potential areas

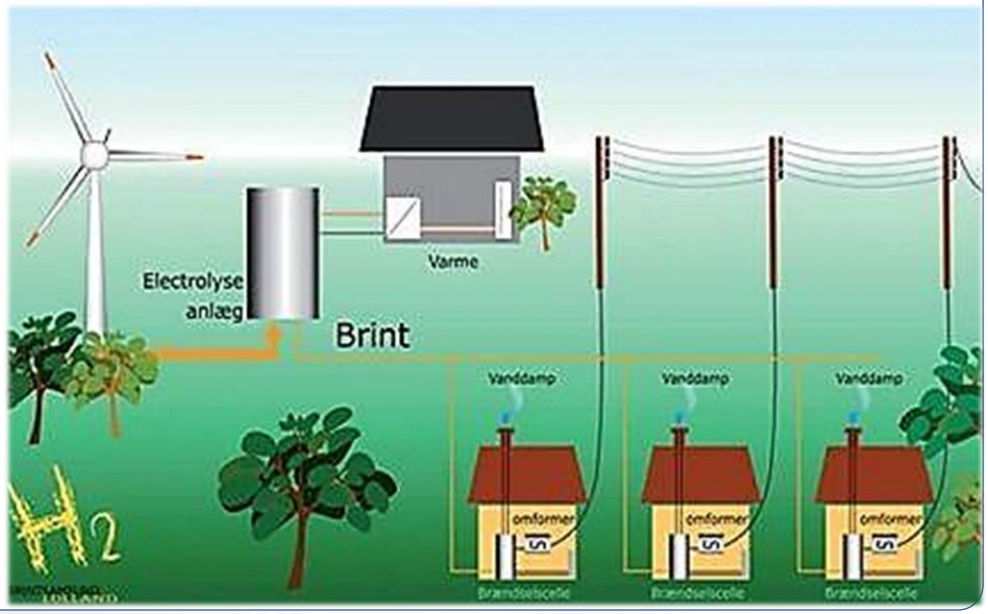
- *Residential Microgrids - 2013 DK Smart Grid Strategy*

  (2015 hourly electricity pricing)

- *Hydrogen Communities (Vestenkov, Lolland) – IRD*
- *Small remote/isolated Microgrids*
- *Large remote Microgrids:*

  Geographical islands

  (70 habited islands in DK)



Samsø Island : 100% Renewable Energy

4,000 people
22 villages
11 x 1MW-WT
10 x 2MW offshore WT

The turbines supply more power than the residents need— Exports 80 million kWh wind-produced electricity annually

Heating plant in Nordby relies on wood chips to create hot water and heat for the villagers.

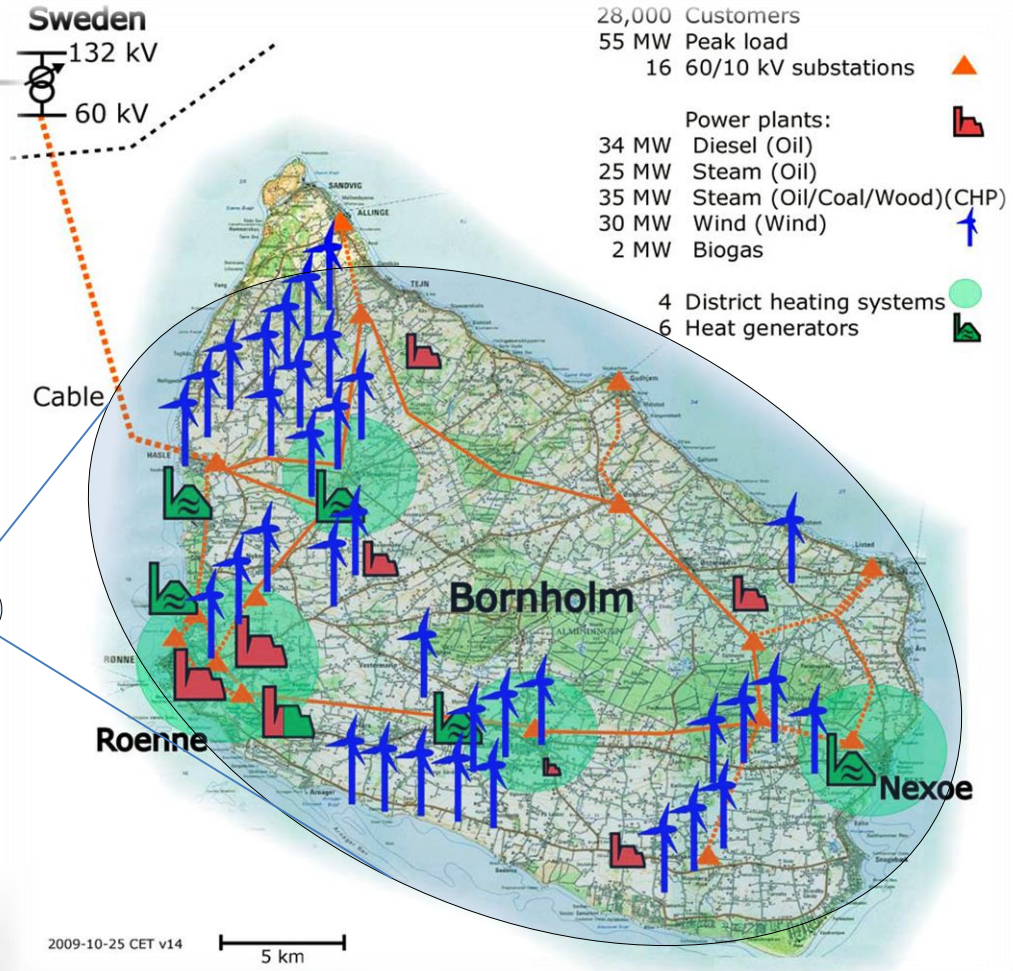
Many rural Samsingers also install highly efficient wood boilers in their homes if they cannot be connected to one of the district heating plants.

70 % of the island's heat and hot water needs

Bornholm Island MicroGrid

The Bornholm power system consists of the following main components:

- 132/60 kV substation in Sweden
- Connection between Sweden and Bornholm
- 60 kV network
- 10 kV network
- 0.4 kV network
- Loads
- Customers
- Generation units
- Control room
- Communication system
- Biogas plant “Biokraft”
- District heating systems



Outline

- Microgrid Research Programme and Laboratories
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- Microgrid Research Activities

MicroGrid Research Programme

EUDP Sino-Danish project proposal

Micro-Grid Technology Research and Demonstration

AALBORG UNIVERSITY DENMARK

Kamstrup

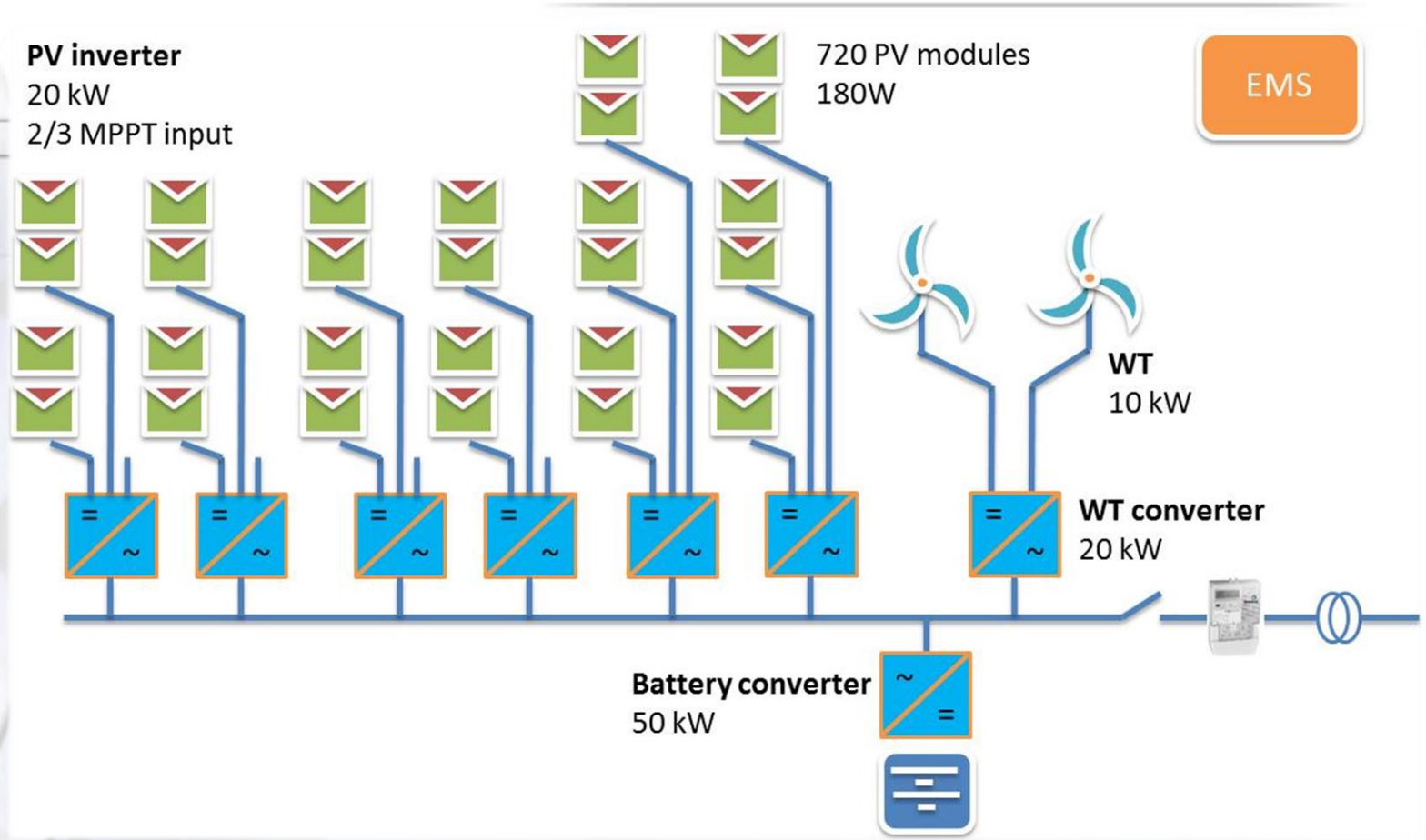
上海太阳能科技有限公司 ShangHai Solar Energy Science & Technology Co.,Ltd.

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

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

Battery energy storage system, power electronics and control.

MicroGrid Research Programme

DSF Sino-Danish project 2014-2017

Intelligent DC Microgrid Living Lab

i-DClab

AALBORG UNIVERSITY
DENMARK

NORTH CHINA ELECTRIC POWER UNIVERSITY

国家电网公司
STATE GRID
CORPORATION OF CHINA

CHINESE ACADEMY OF SCIENCES

The Danish Council for Strategic Research

Intelligent DC Microgrid Living Lab

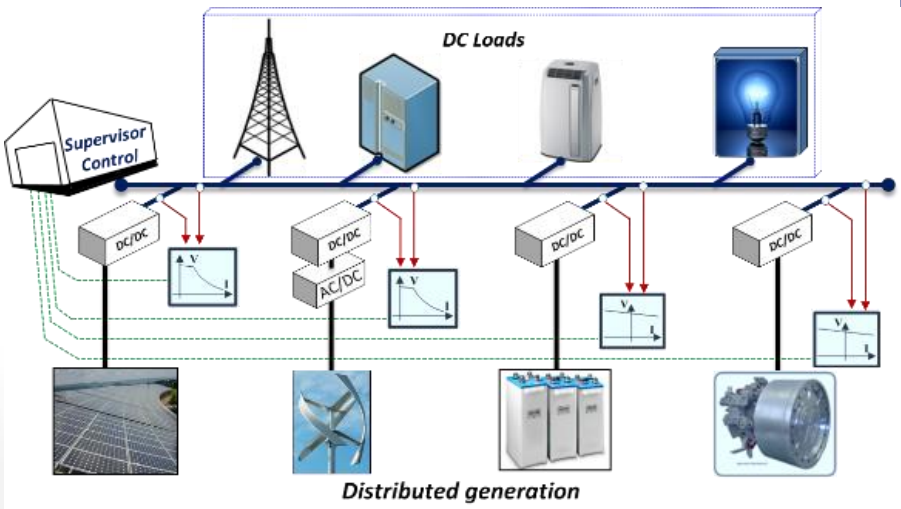
- **Phase I: Design, modelling and control.**
- **Phase II: Coordination control** schemes between microgrid elements, including **communication** systems and **energy management systems** for DC microgrids.
- **Phase III:** Creation of **two Living Labs** as a user-centred research concept, to test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

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

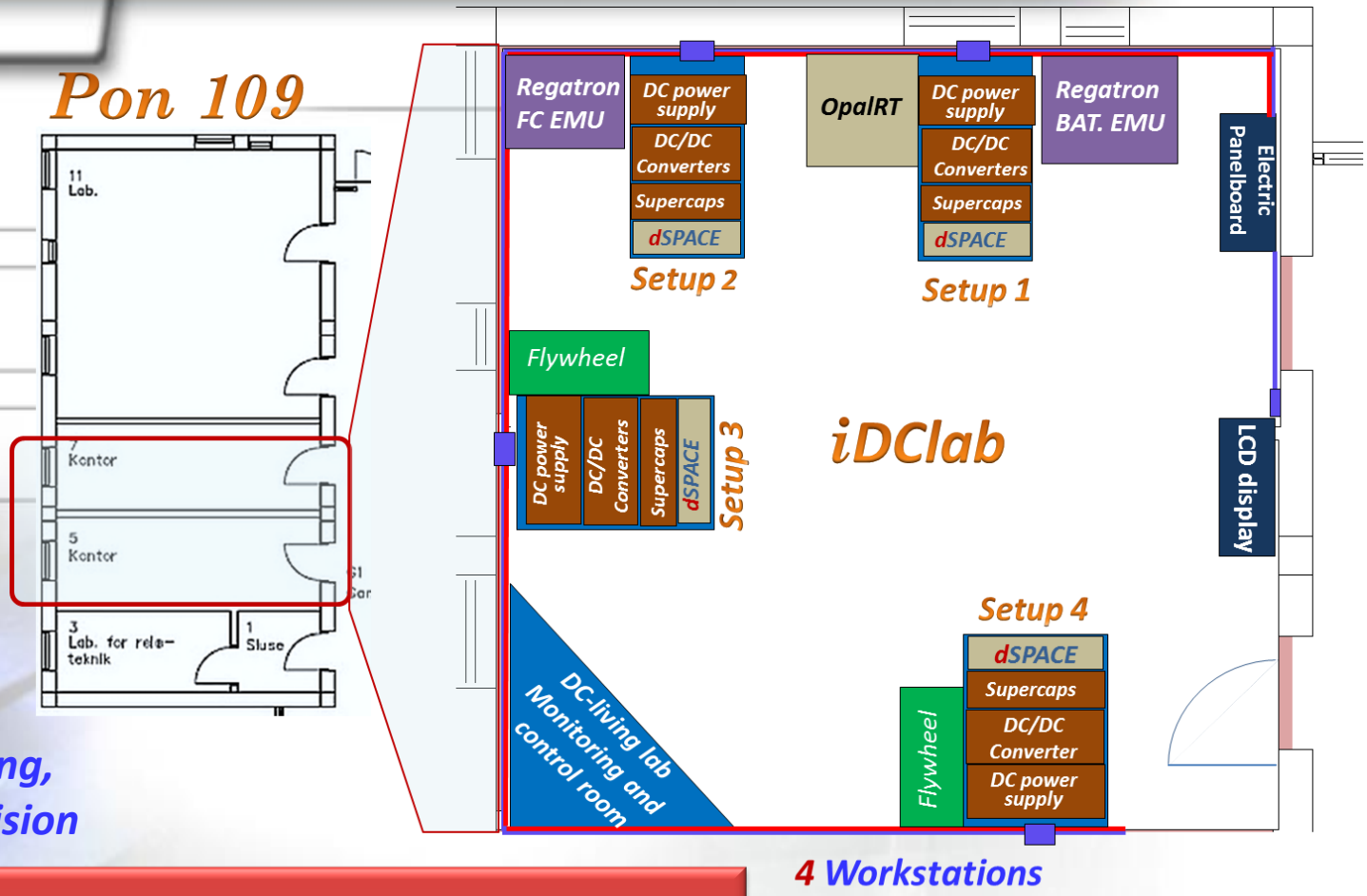
to research and test DC distribution for **1-2 family houses**

- 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 living lab - iDClab



5 Workstations

- FC emulators
- Battery emulators
- Flywheels
- Supercaps
- Dedicated DC/DC converters
- Constant power loads
- Real-time monitoring, Control and supervision

1 Setup for
Demonstration of DC-home with Real DC appliances.

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

AALBORG UNIVERSITET

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

Future Residential LVDC Power Distribution Architectures

Danish Agency for Science Technology and Innovation
Ministry of Science Technology and Innovation

This project will be done in cooperation with:

International ranked research institutions

And the Danish Companies

kk-electronic a/s

NEOGRID TECHNOLOGIES

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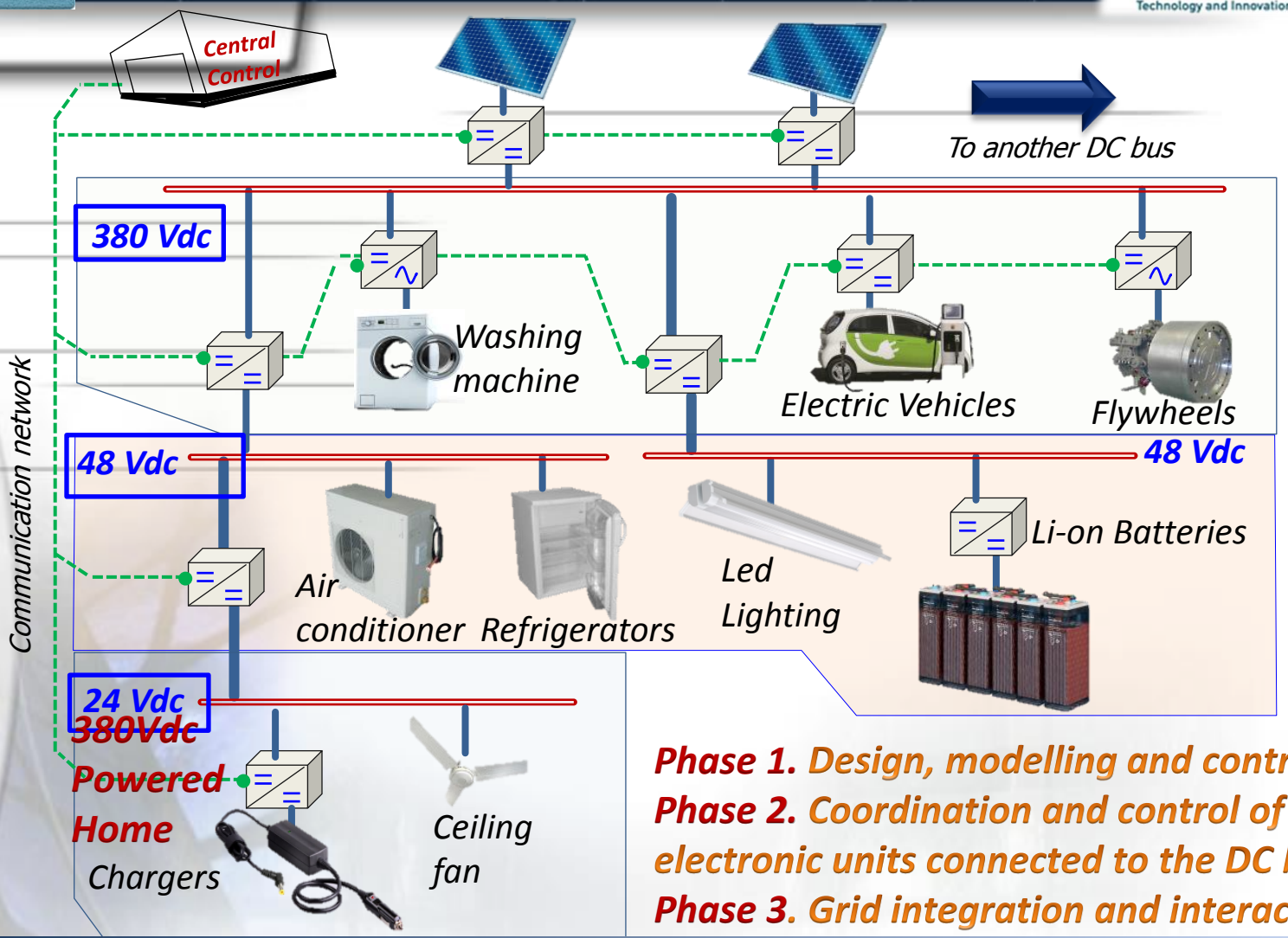

Phase 1. Design, modelling and control
Phase 2. Coordination and control of power electronic units connected to the DC bus
Phase 3. Grid integration and interactivity

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

Future Residential LVDC Power Distribution Architectures

Danish Agency for Science Technology and Innovation
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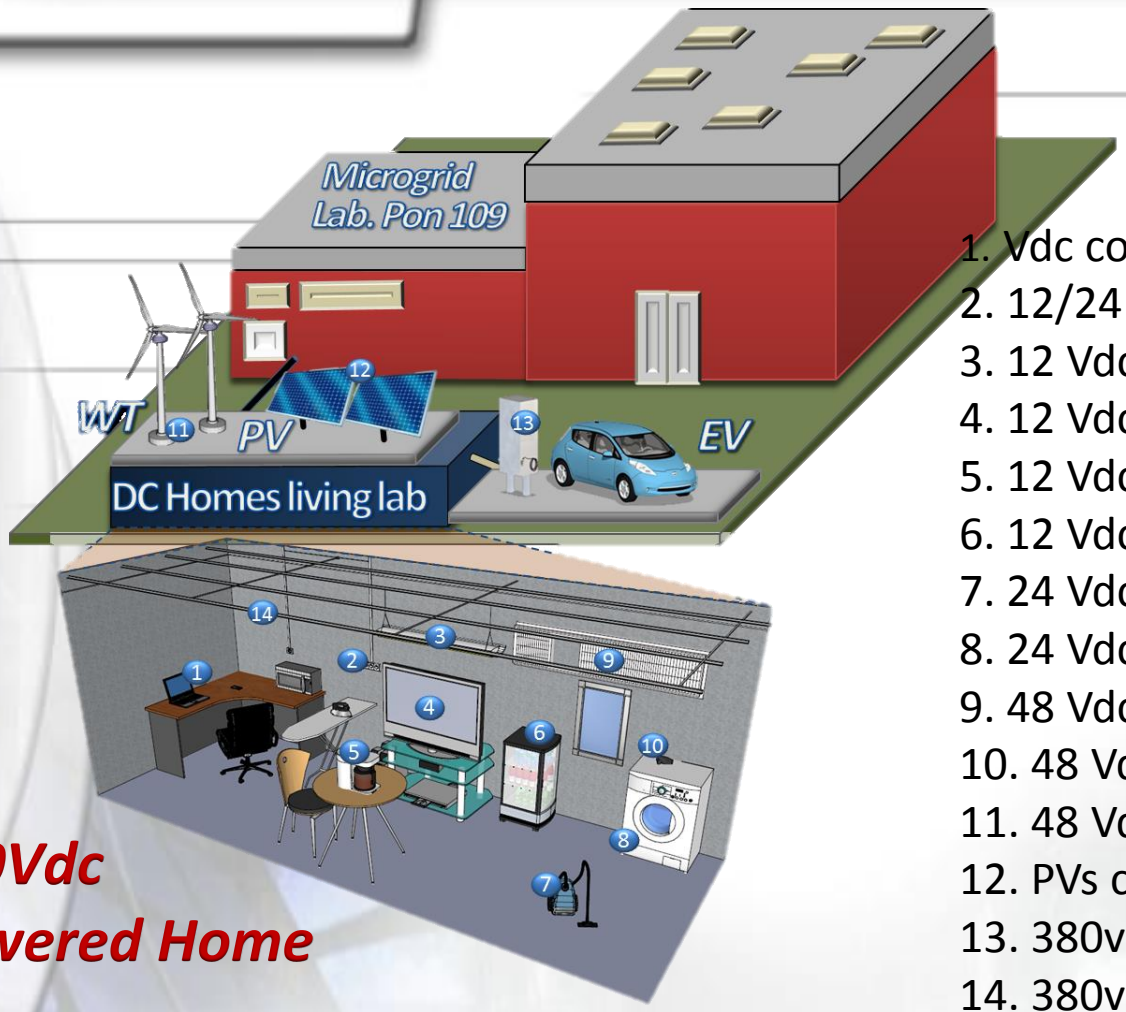


380Vdc Powered Home

1. Vdc consumer electronics
2. 12/24 Vdc wall sockets
3. 12 Vdc LED lighting
4. 12 Vdc coffee maker
5. 12 Vdc refrigerator
6. 12 Vdc hair dryer
7. 24 Vdc vacuum cleaner
8. 24 Vdc home entertainment system
9. 48 Vdc washing machine
10. 48 Vdc air conditioner
11. 48 Vdc whisper wind turbine
12. PVs connected in 380vdc bus bar
13. 380vdc charger
14. 380vdc busway distribution system

MicroGrid Research Programme

ERANET project 2014-2016

Flexible electric vehicle charging infrastructure Flex –ChEV

AALBORG UNIVERSITY
DENMARK

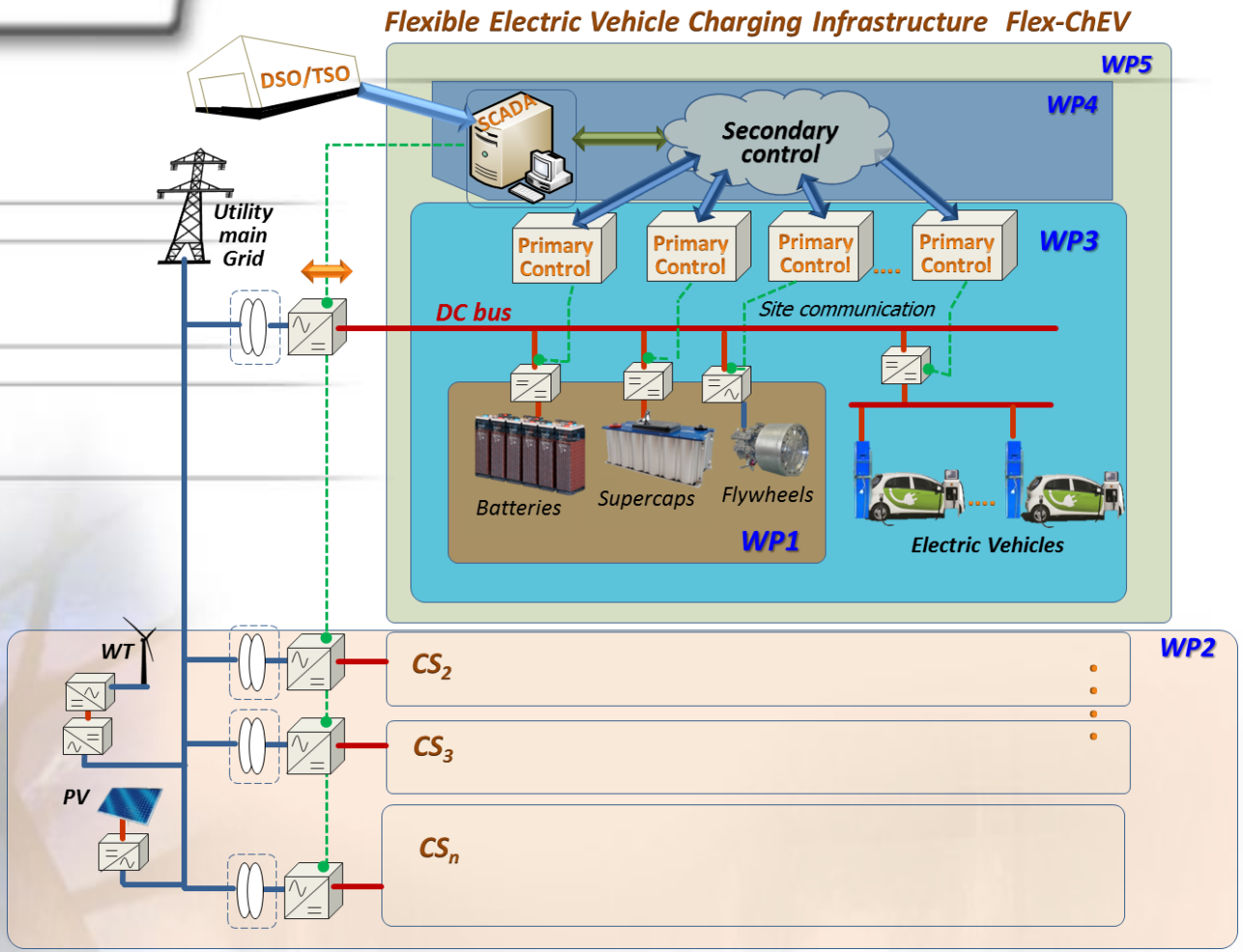
HØGSKOLEN I NARVIK

UNIVERSITAS STUDIORUM ZAGRABIENSIS MDCLXIX

AALBORG UNIVERSITET

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

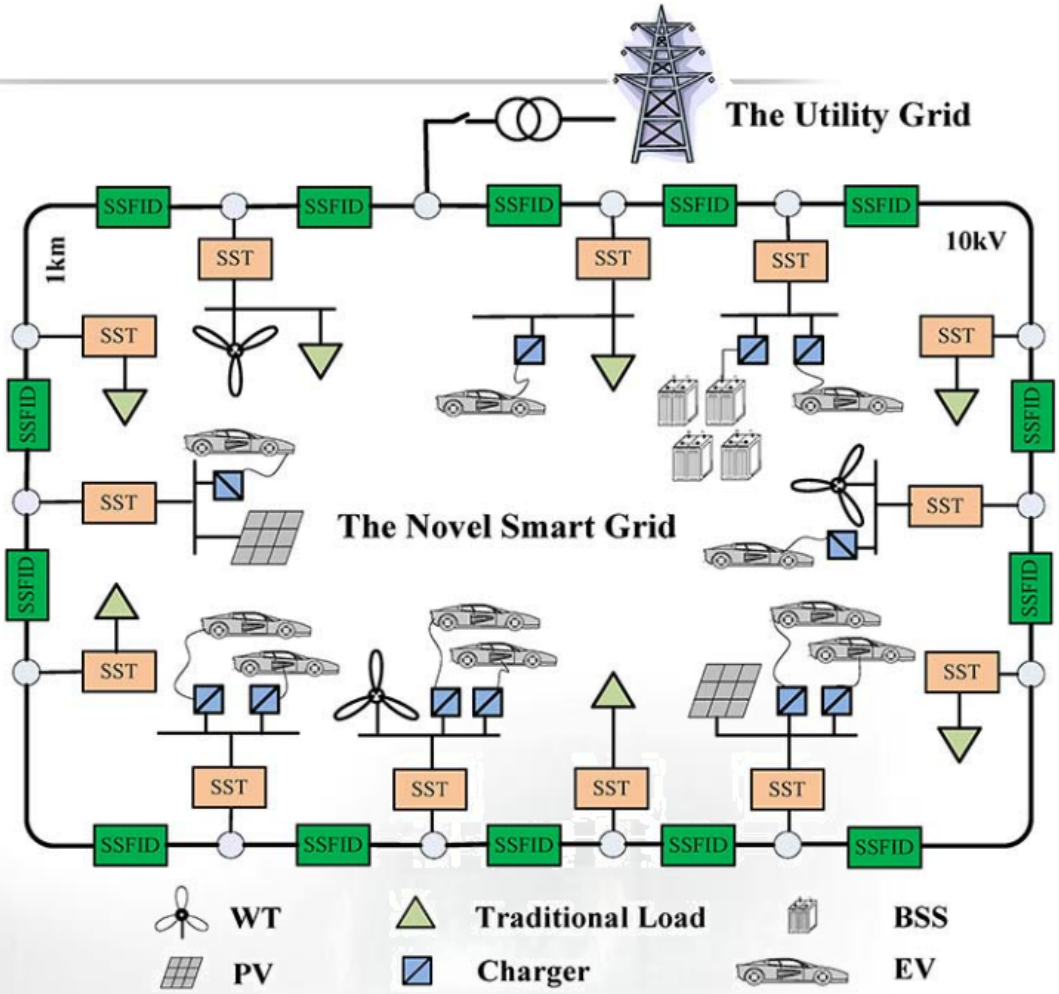
Flexible electric vehicle charging infrastructure Flex –ChEV



Flexible electric vehicle charging infrastructure Flex –ChEV

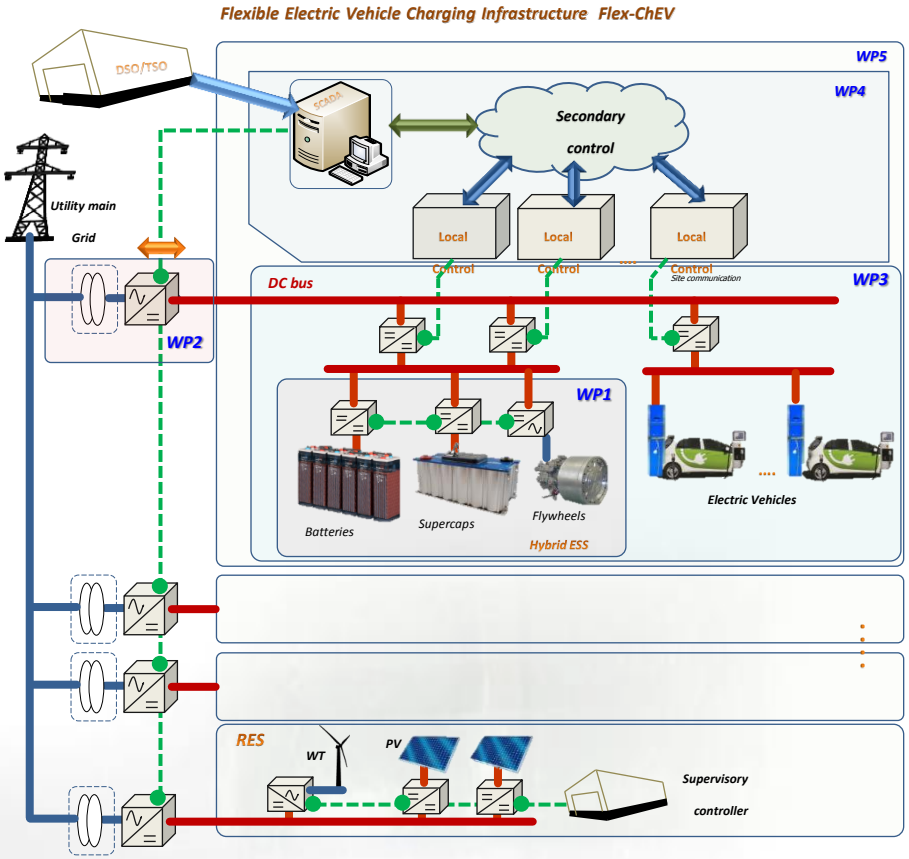
Functionalities of the EVCS

- ✓ P/Q coordination
- ✓ Frequency participation
- ✓ Voltage support
- ✓ Unbalance compensation
- ✓ Harmonics sharing

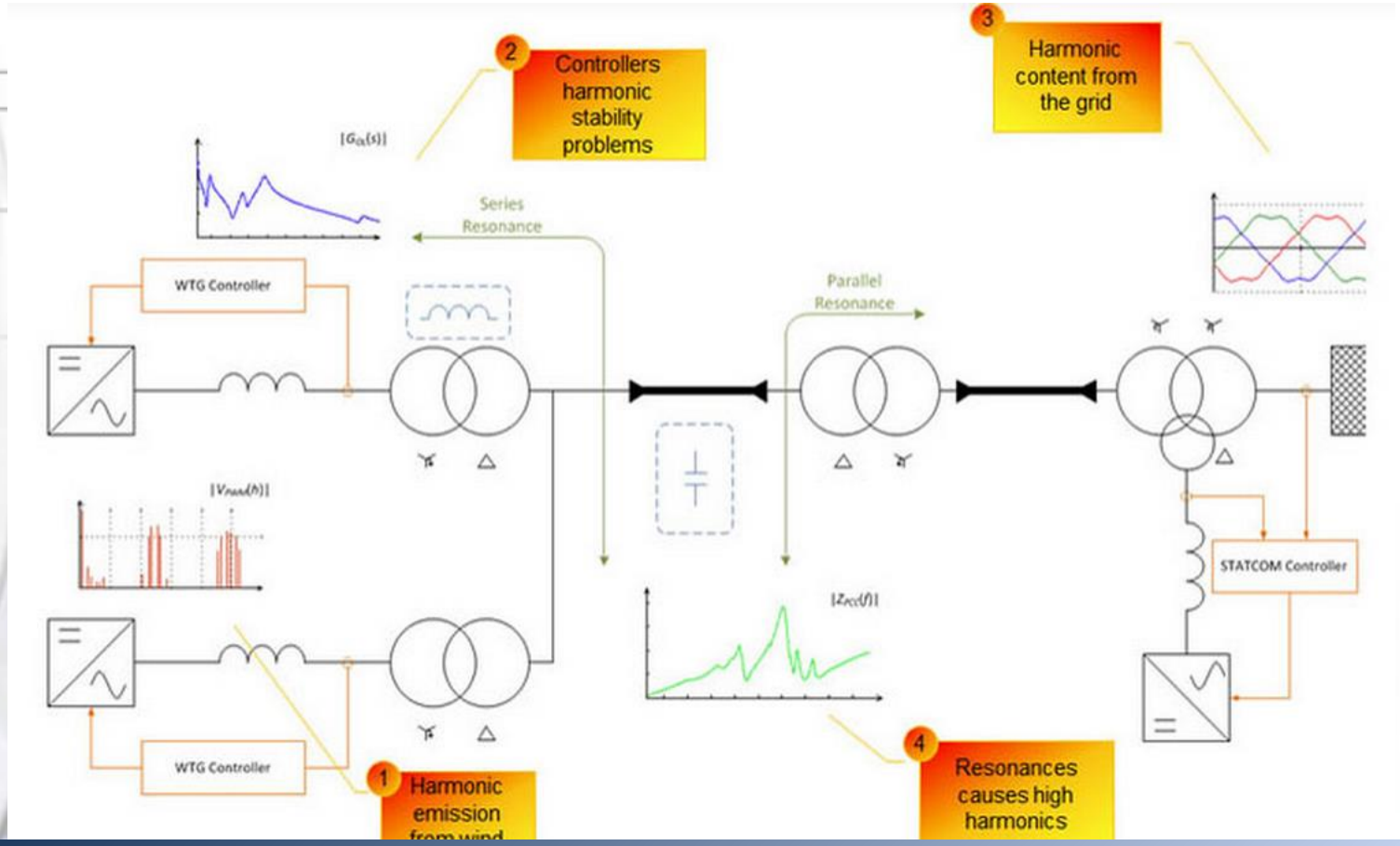


Flexible electric vehicle charging infrastructure Flex –ChEV

Electric charging station in Iwate, Shizuoka, Japan.

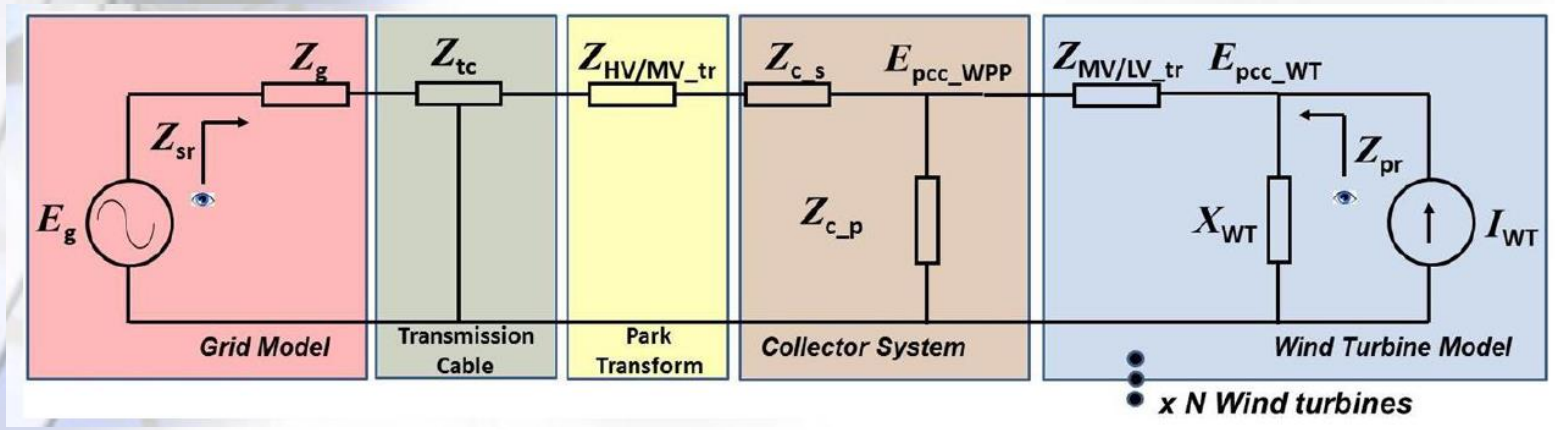


Active Filter Functionalities for Power Converters in Wind Power Plants



Active Filter Functionalities for Power Converters in Wind Power Plants

- Problem overview: Harmonics (emissions/interactions) + electrical resonances cause critical problems in Wind Power Plants
- Industrial Partners are very interested on solve this problems: **Operation failures give rise to economical losses!**
- How to tackle the problem:
  1. **Detailed modeling of the system in time and frequency domain.**
  2. **Use of passive filters.**
  3. **Use of active and hybrid filters (new devices).**
  4. **Improving the functionality of existing power electronics devices: WT and STATCOM control enhancement.**
  5. **Improving the functionality of existing power electronics: WT, STATCOM control enhancement in collaboration with passive filters.**



Future industrial projects

Modular design of UPS systems

Control of solar-concentrator power plants

Deployment of energy storage systems in maritime applications (drilling rigs and vessels)

Research Challenges in MicroGrid technologies

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MicroGrid
RESEARCH
PROGRAMME

Thank you for your attention!