MICROGRIDS IN DENMARK

The Faroe Islands Project

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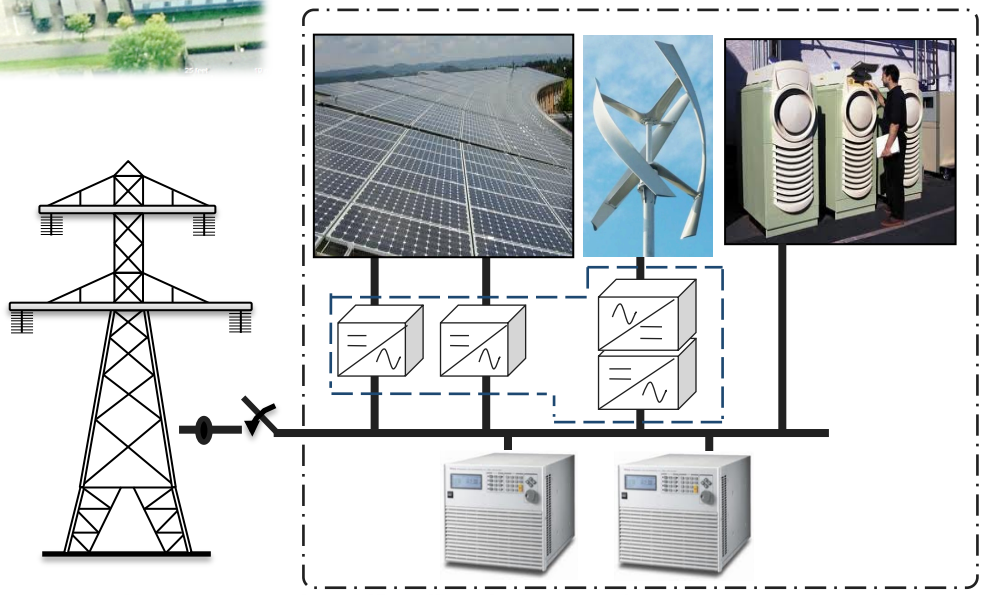

Outline

1. Denmark – a paradigm of decentralized electrical energy system
2. MicroGrid Research in Aalborg University
3. Faroe Islands Wind Powered MicroGrid Project

Outline

1. **Denmark – a paradigm of decentralized electrical energy system**
2. MicroGrid Research in Aalborg University
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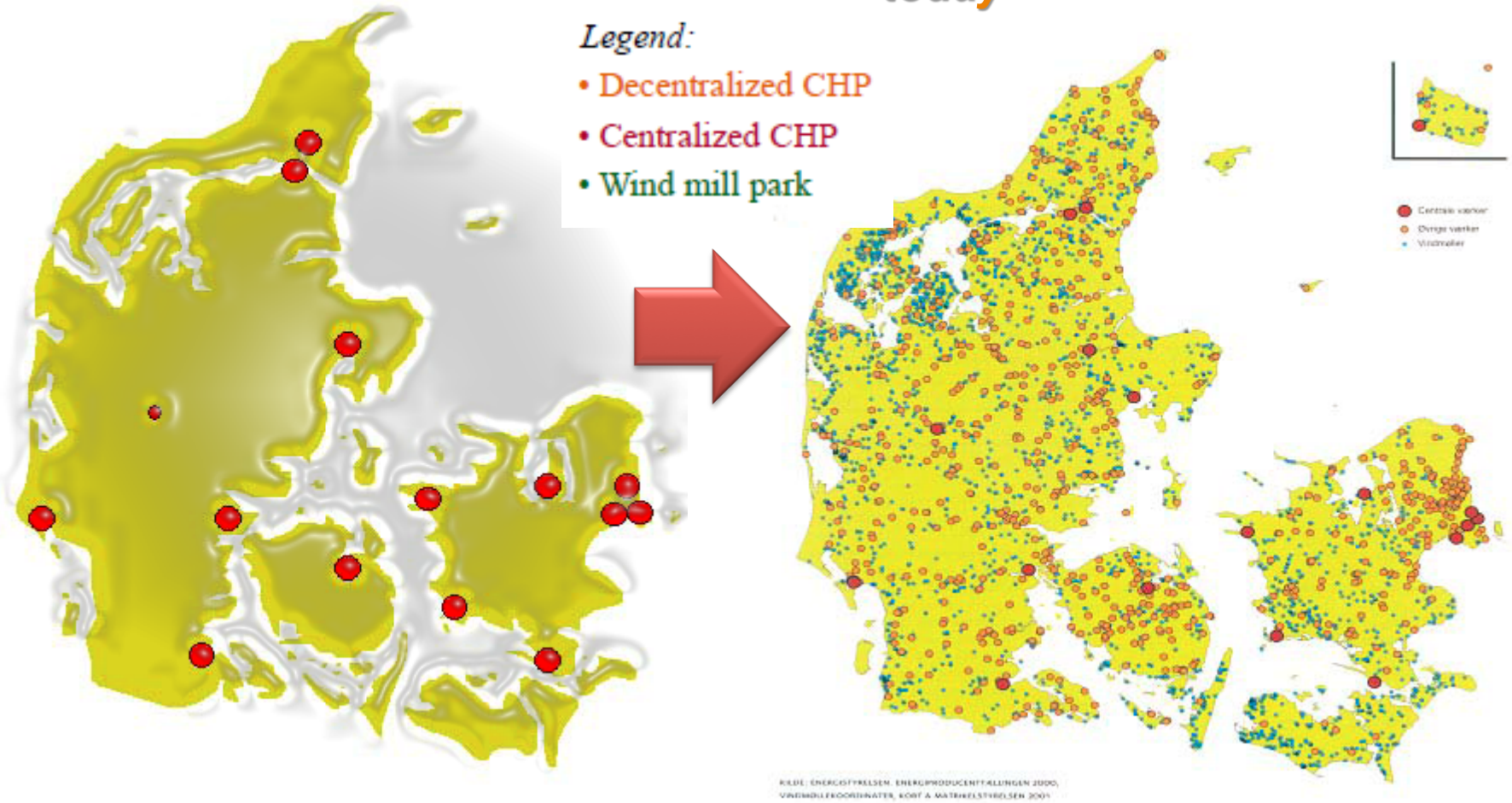
Denmark, Grønland, and Faroe Islands

Area	
Denmark	43,094 km^2
Greenland	2,166,086 km^2
Faroe Islands	1,399 km^2
Population	5,543,453
Greenland	57,695
Faroe Islands	49,483

From Centralized to Decentralized CHP

Centralized production in the mid 80's ***Decentralized production of today***

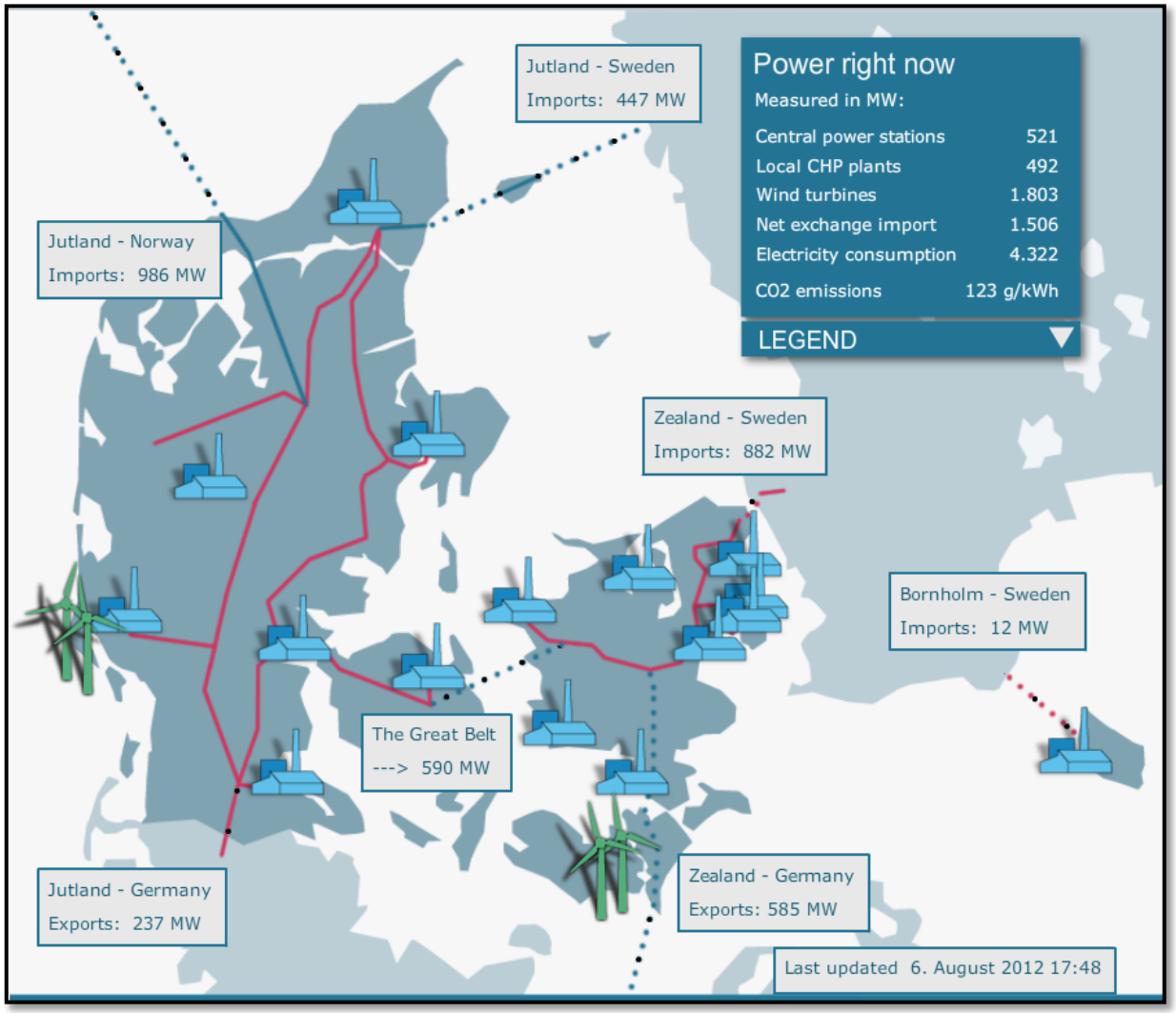


District heating and CHP have reduced Denmark's CO2-emission by 1/5.

Energinet.dk

Energinet.dk

- *Is the Danish national transmission system operator for electricity and natural gas.*
- *It is an independent public enterprise owned by the Danish state under the Ministry of Climate and Energy.*



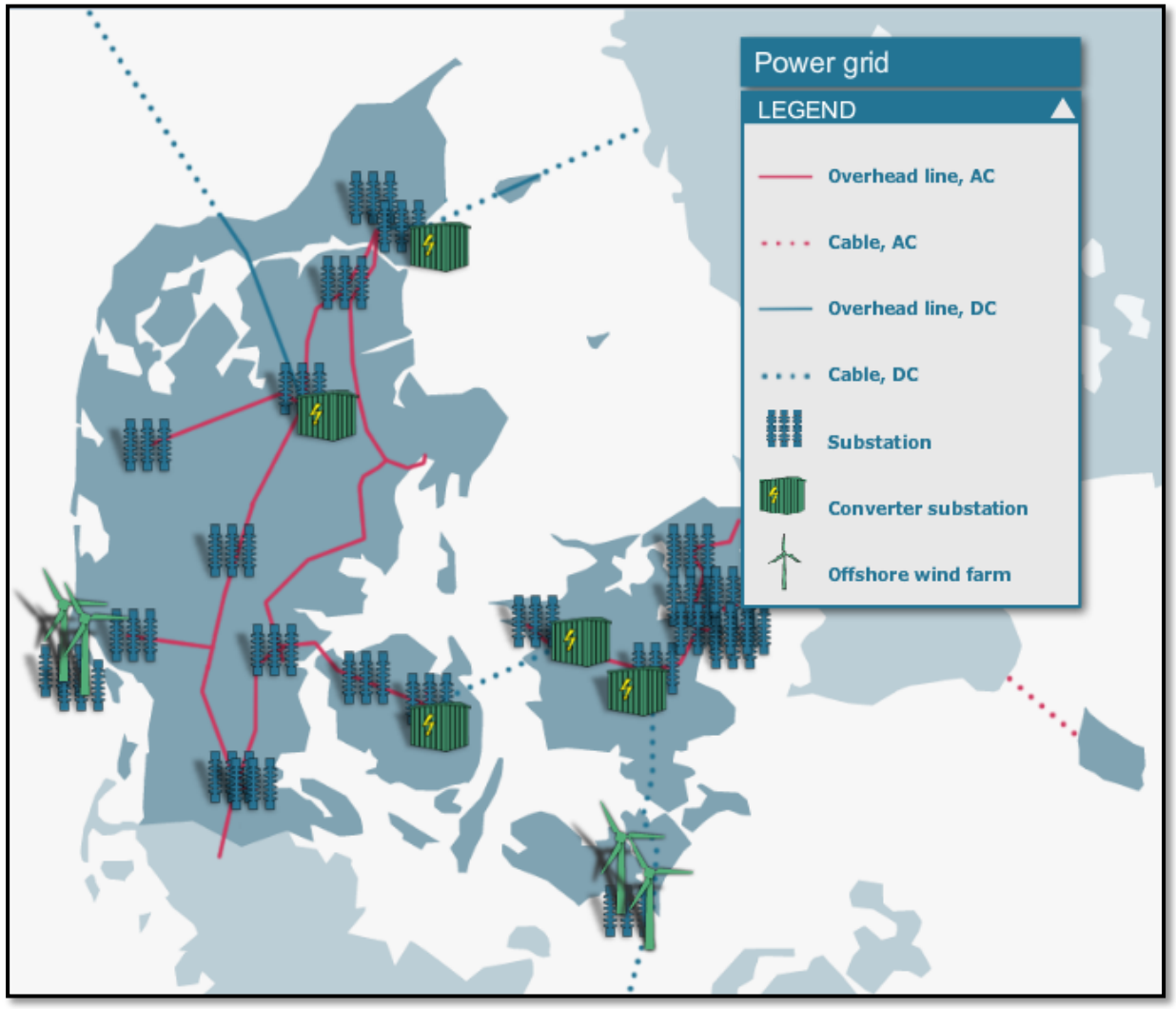
energinet.dk

Energinet.dk buys the following ancillary services in **Western Denmark**:

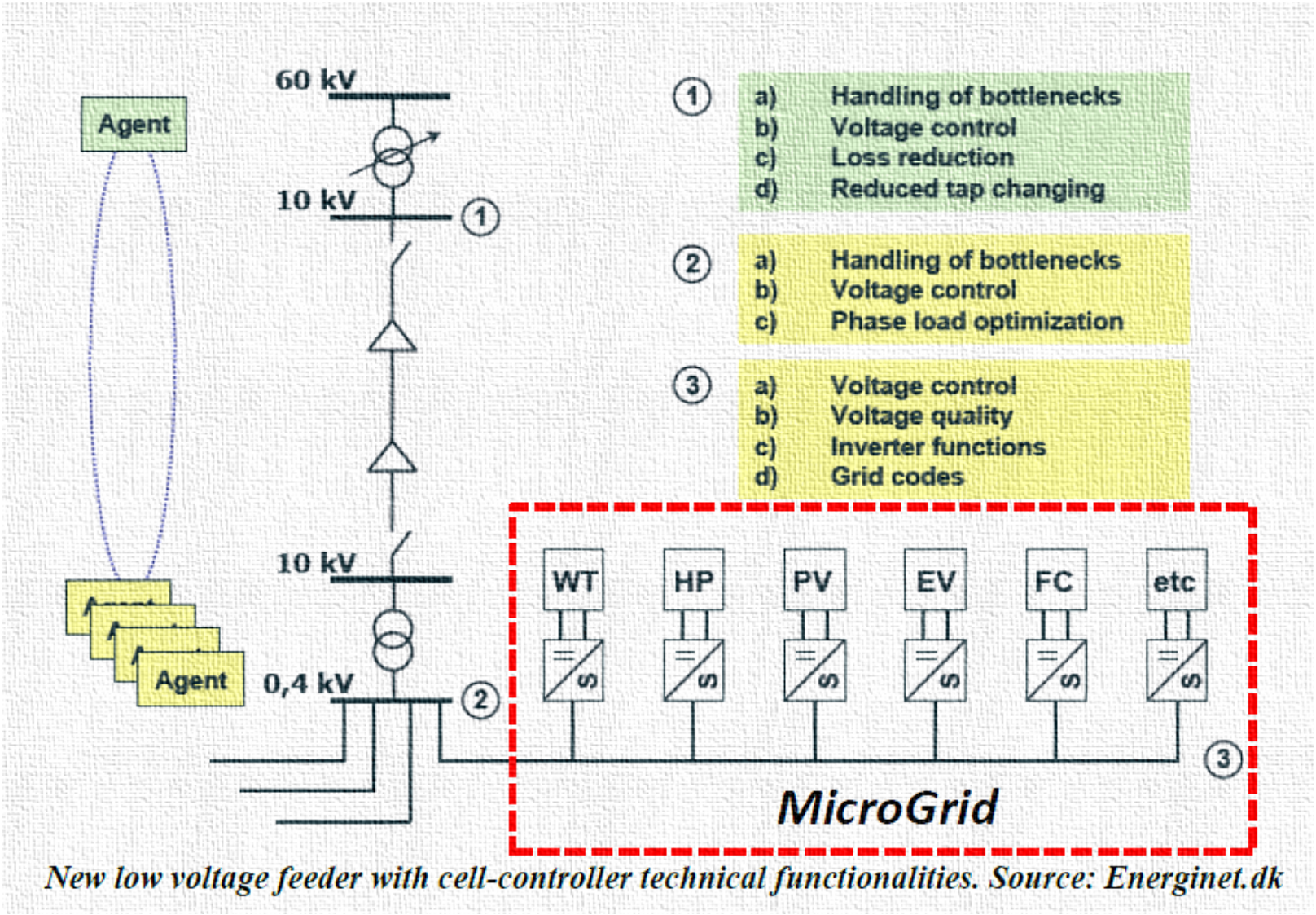
- Primary reserves
- Secondary reserves, LFC (Load Frequency Control)
- Black-start capability
- Manual reserves
- Short-circuit power, reactive reserves and voltage control.

Energinet.dk buys the following ancillary services in **Eastern Denmark**:

- Frequency-controlled disturbance reserve
- Frequency-controlled normal operation reserve
- Manual reserves
- Short-circuit power, reactive reserves and voltage control.



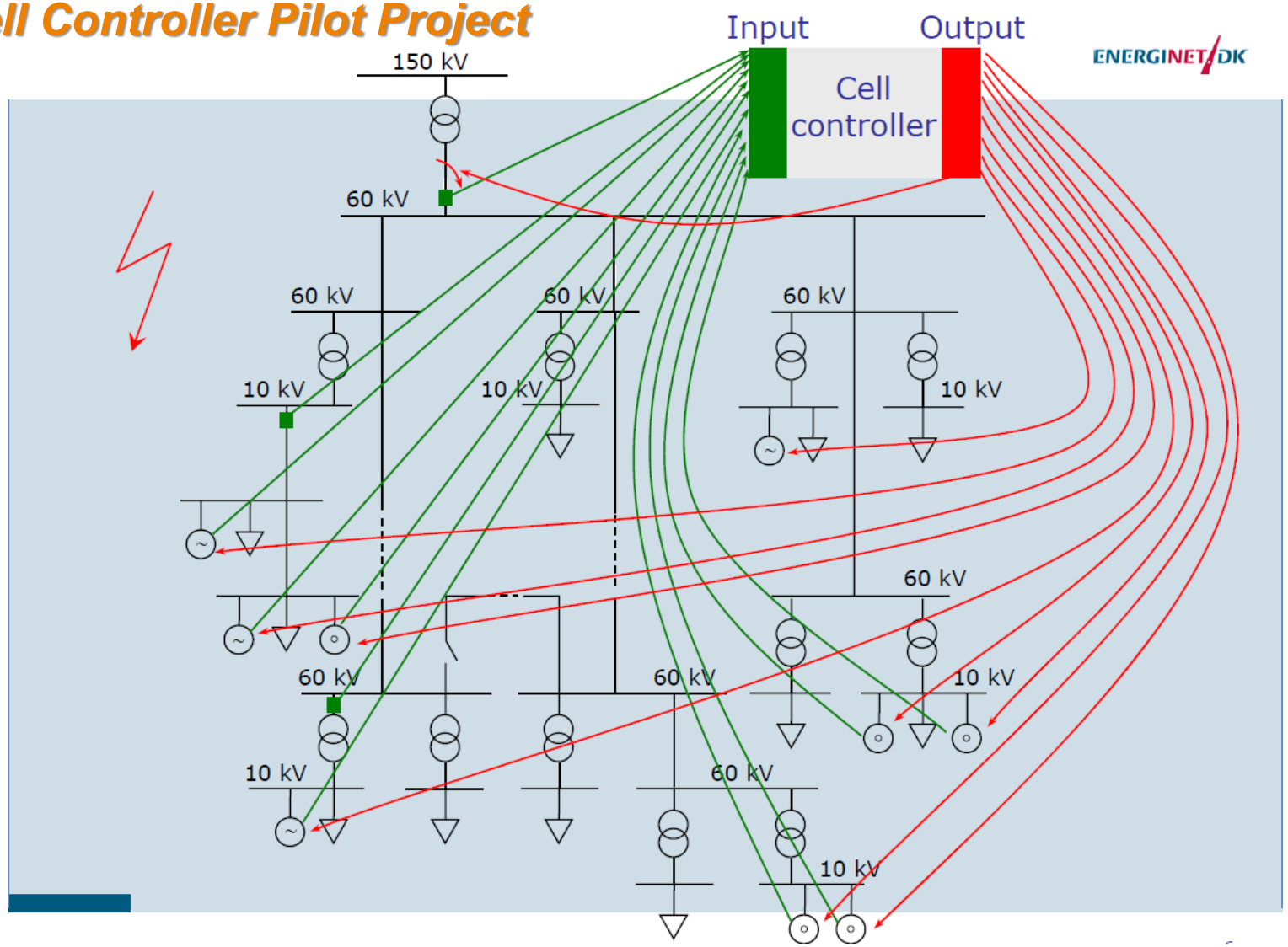
Denmark Grid Concept



New low voltage feeder with cell-controller technical functionalities. Source: Energinet.dk

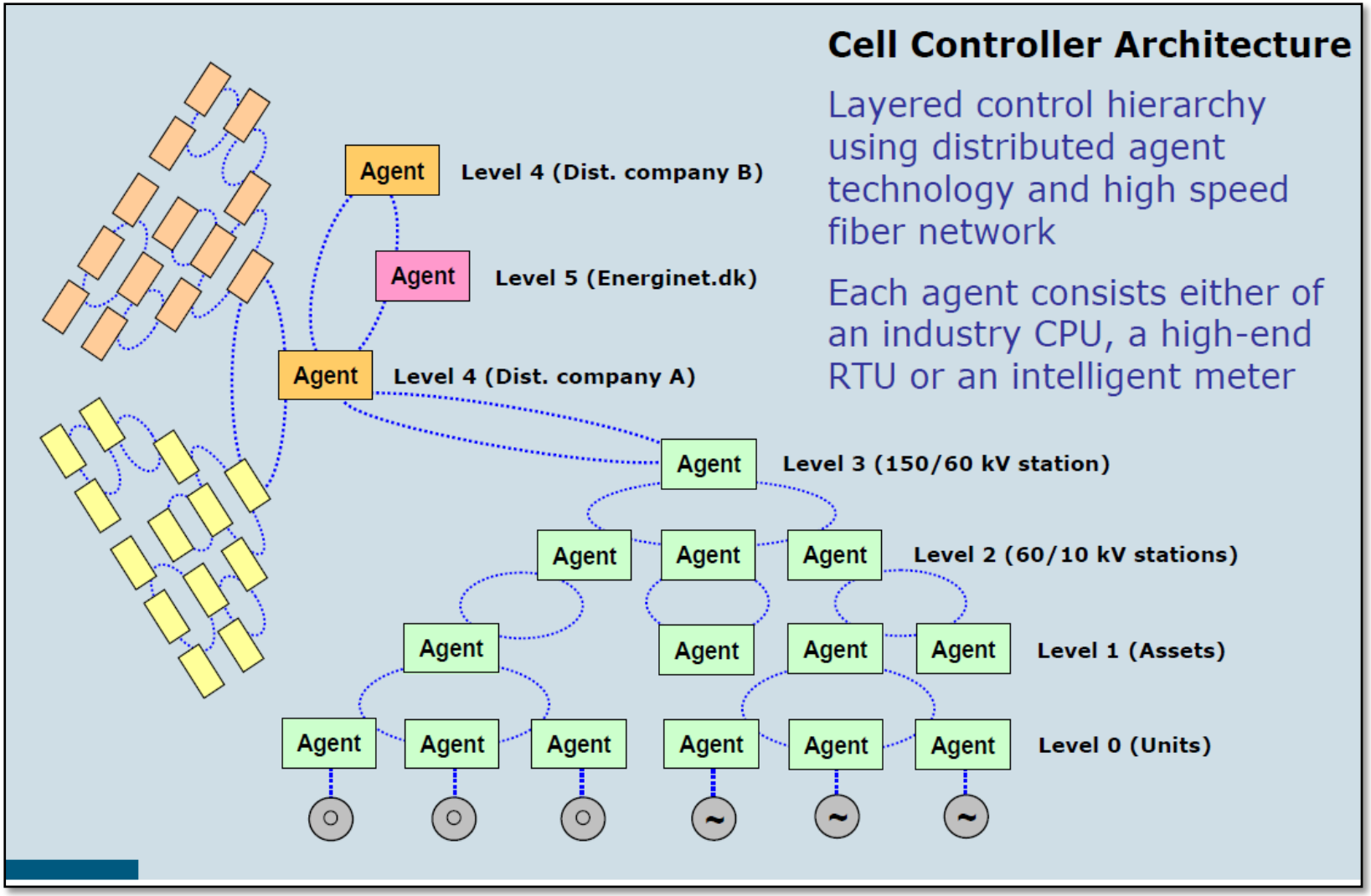
Denmark Grid Concept

Cell Controller Pilot Project



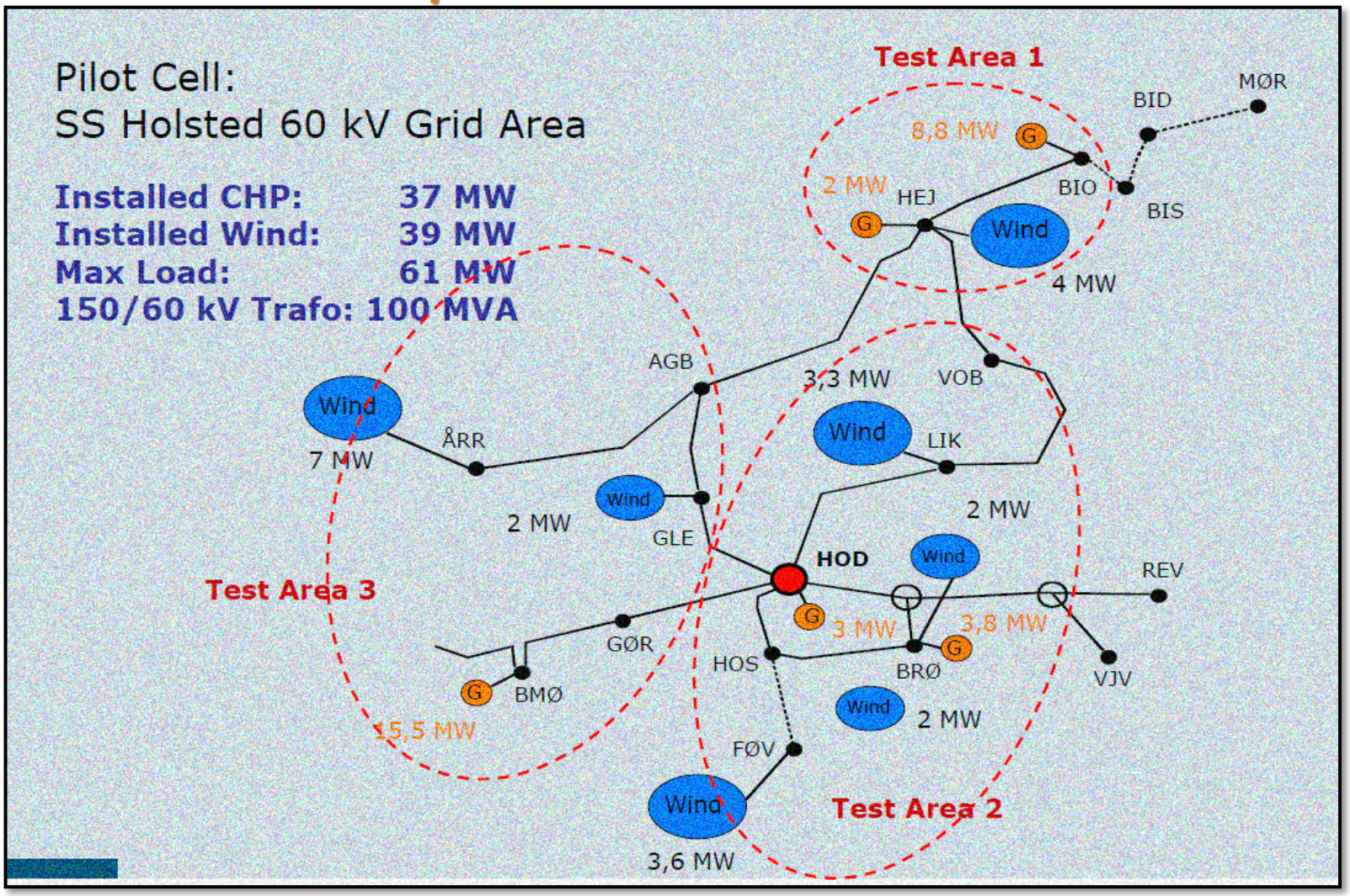
Denmark Grid Concept

Cell Controller Pilot Project



Denmark Grid Concept

After a total system collapse the Cell black-starts itself to a state of controlled island operation



Samsø Island : 100% Renewable Energy

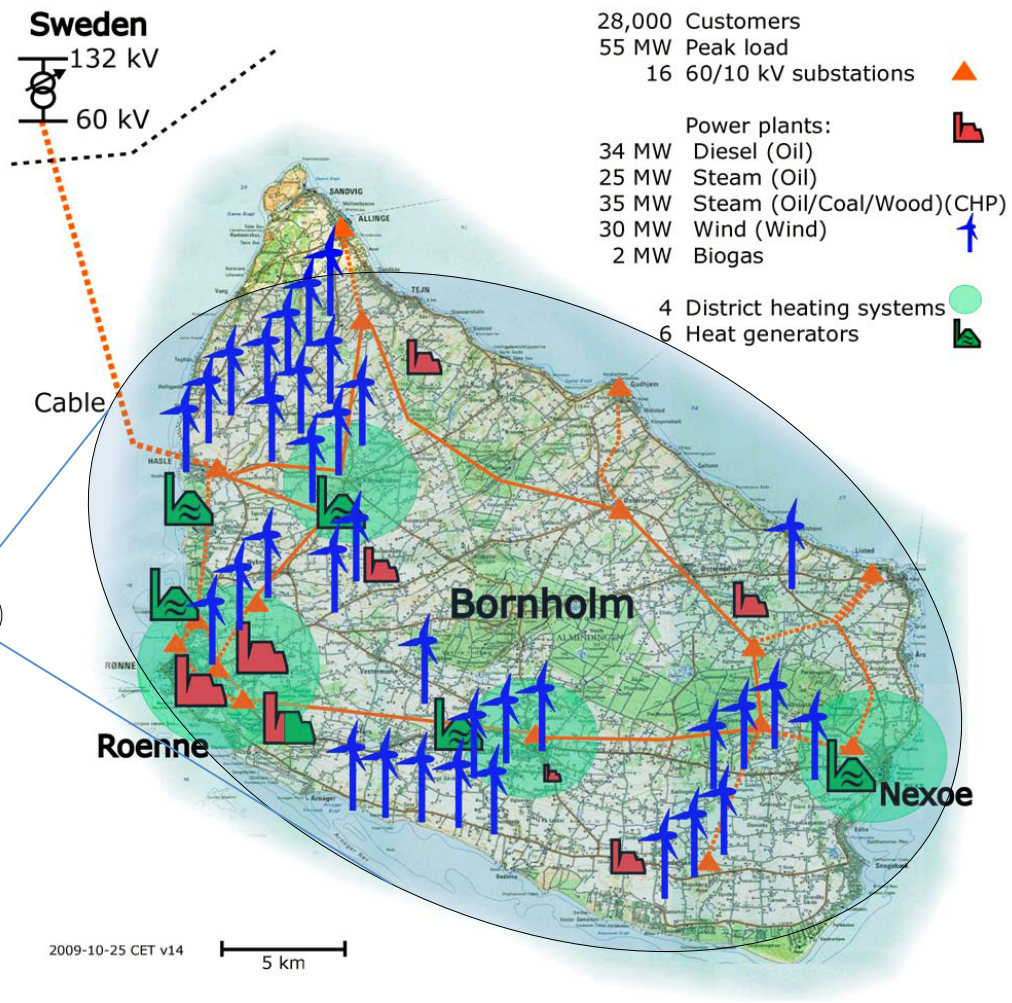
4,000 people
22 villages
11 x 1MW-WT
10 x 2MW offshore WT

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

1. Denmark – a paradigm of decentralized electrical energy system

2. **MicroGrid Research in Aalborg University**

3. Faroe Islands Wind Powered MicroGrid Project

Aalborg University

Aalborg University was created through a merger of a number of well-established institutions, combined with the establishment of a number of new faculties in 1974.
Aalborg University was characterised by its well-reputed education form of **problem based project work** – also known as the ***Aalborg model***, and by extensive collaboration with the surrounding society. The number of students is around 15,000.

Institute of Energy Technology

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Department of Energy Technology

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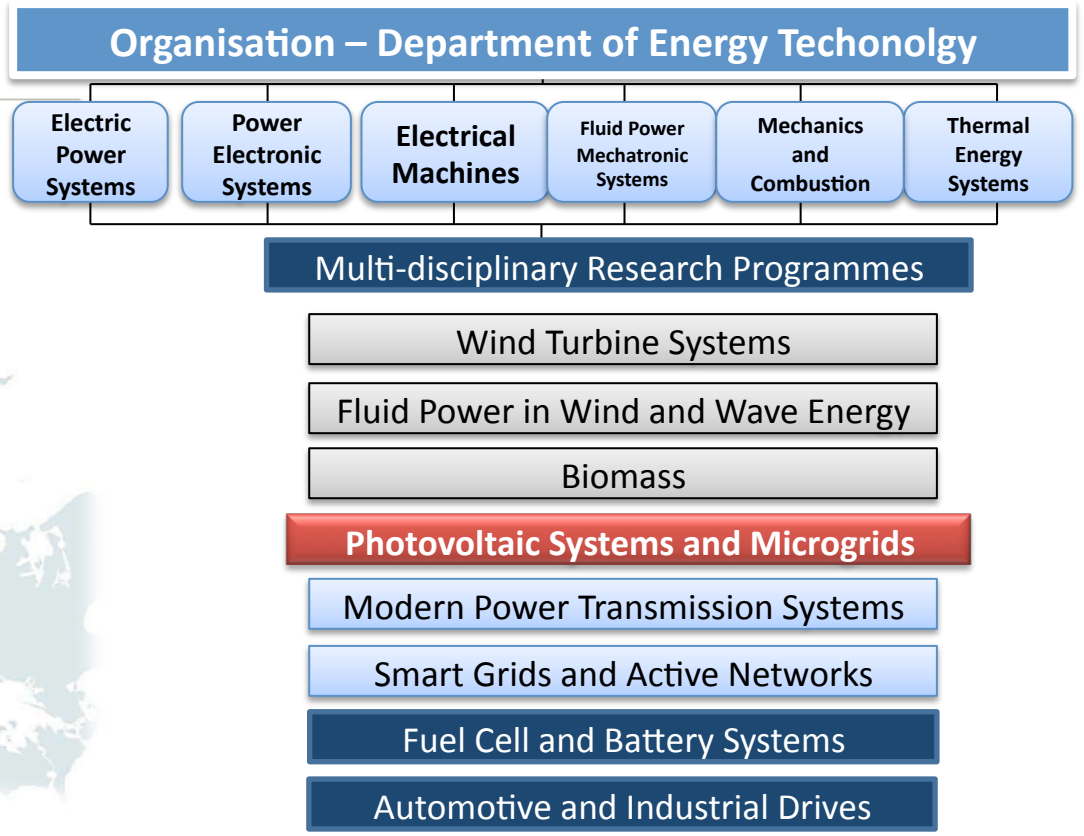


- *Approximately 40 faculty members*
- *Approximately 70 PhD students*
- *More than 20 guest researchers*
- *Approximately 20 TAPs (technical administrative employees)*
- *Approximately 250 students*
- *More than 50 on-going collaboration projects*
- *Approximately 50% of the turnover comes from external projects*

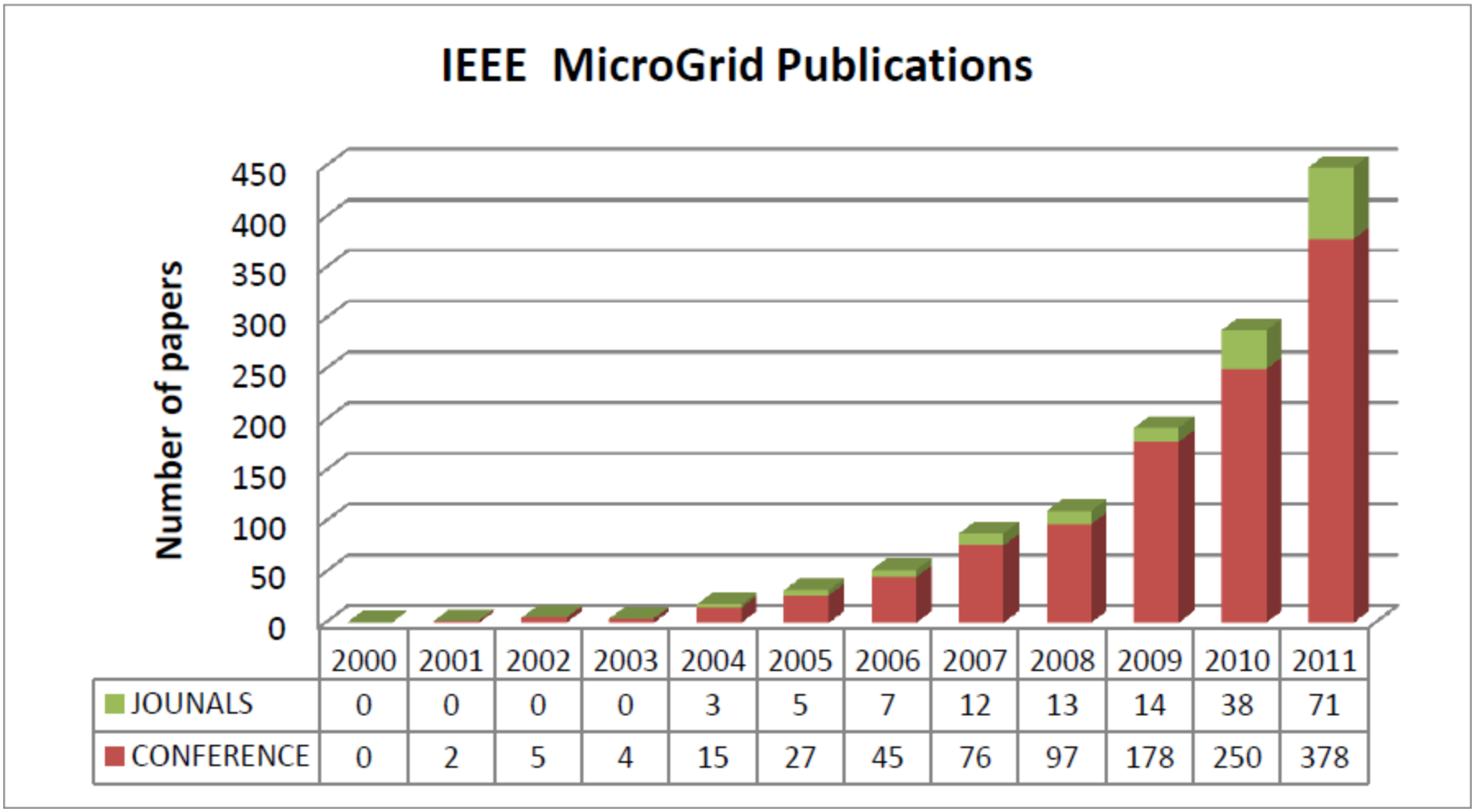
Institute of Energy Technology

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

Research Programmes

Wind Power Systems,	Prof. Zhe Chen
Fluid Power in Wind and Wave Energy,	Ass. Prof. Henrik C. Pedersen
Biomass,	Prof. Lasse Rosendahl
Photovoltaic Systems,	Prof. Remus Teodorescu
Modern Power Transmission Systems,	Prof. Claus Leth Bak
Smart Grids and Active Networks,	Ass. Prof. Birgitte Bak-Jensen
Fuel Cell and Battery Systems,	Prof. Søren Knudsen Kær
Automotive and Industrial Drives,	Ass. Prof. Kaiyuan Lu
Efficient and Reliable Power Electronics	Prof. Frede Blaabjerg
Thermoelectrics,	Research Ass. Paw Mortensen
Green Buildings,	Ass. Prof. Carsten Bojesen
Microgrids,	**Prof. Josep M. Guerrero**

MicroGrids Reports

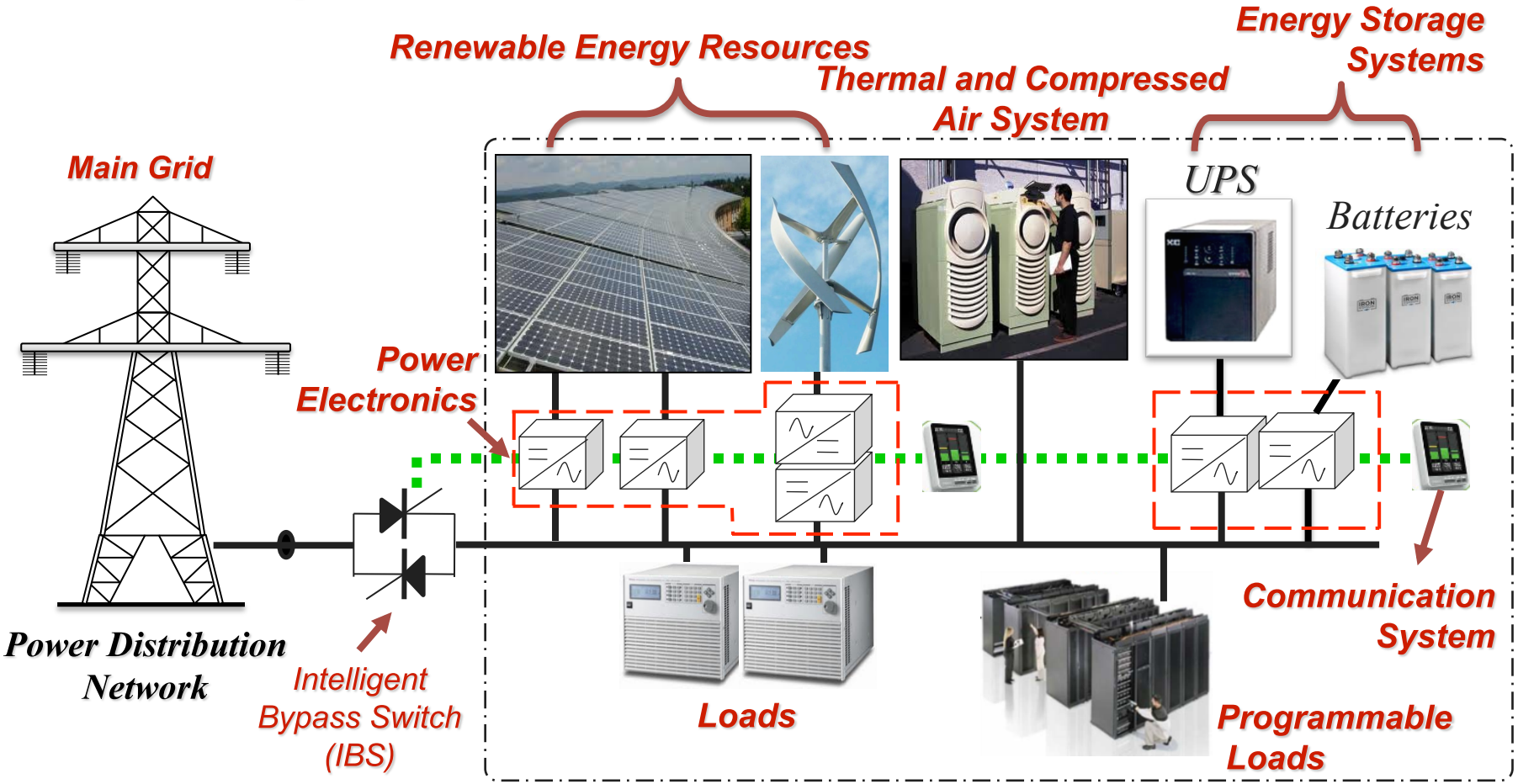


	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
JOUNALS	0	0	0	0	3	5	7	12	13	14	38	71
CONFERENCE	0	2	5	4	15	27	45	76	97	178	250	378

MicroGrids Activities

➢ General aspects of a MicroGrid: "Definition and Operation"

What is a Microgrid?



MicroGrids Activities

➢ *General aspects of a MicroGrid: "Definition and Operation"*

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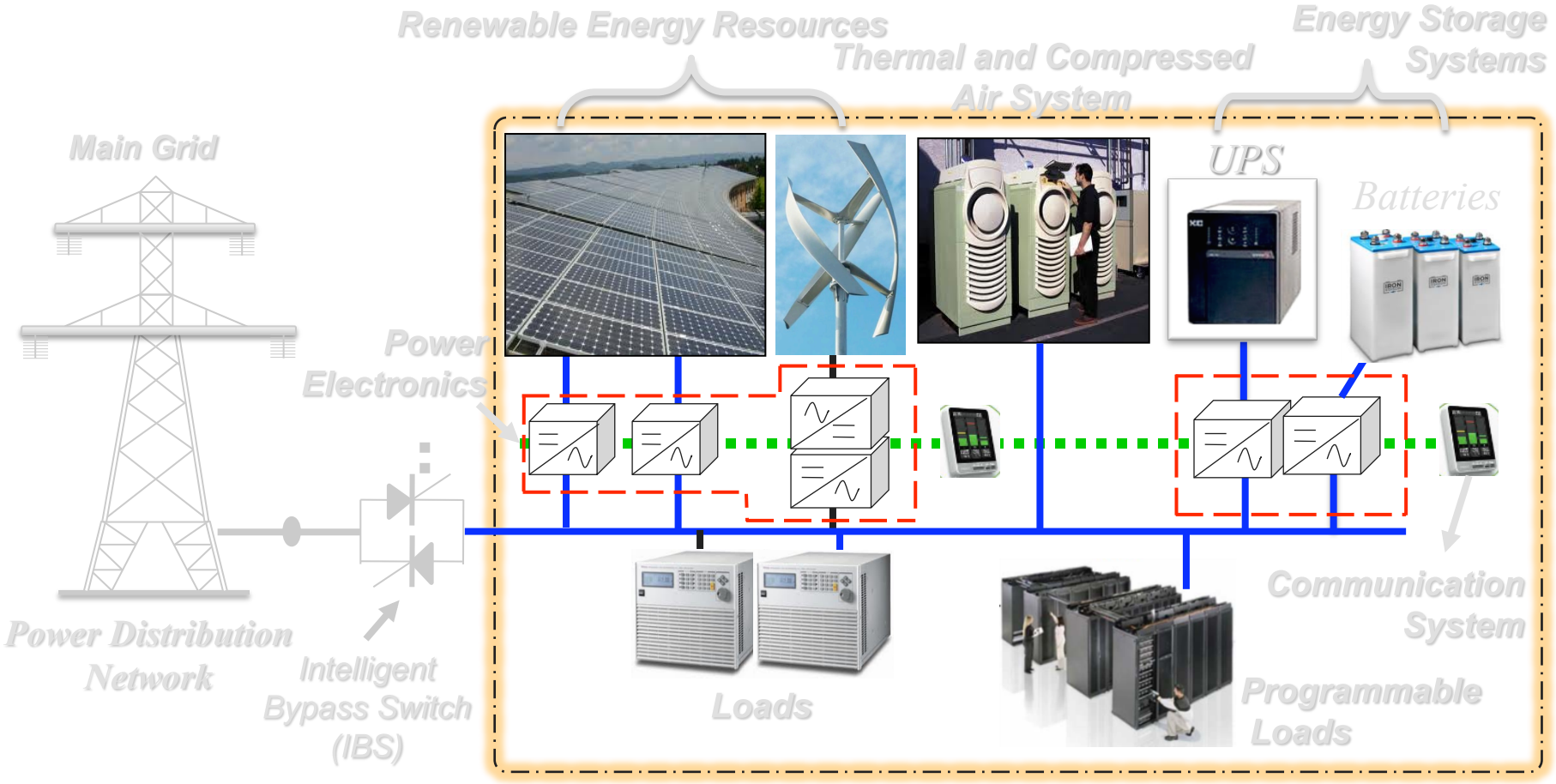
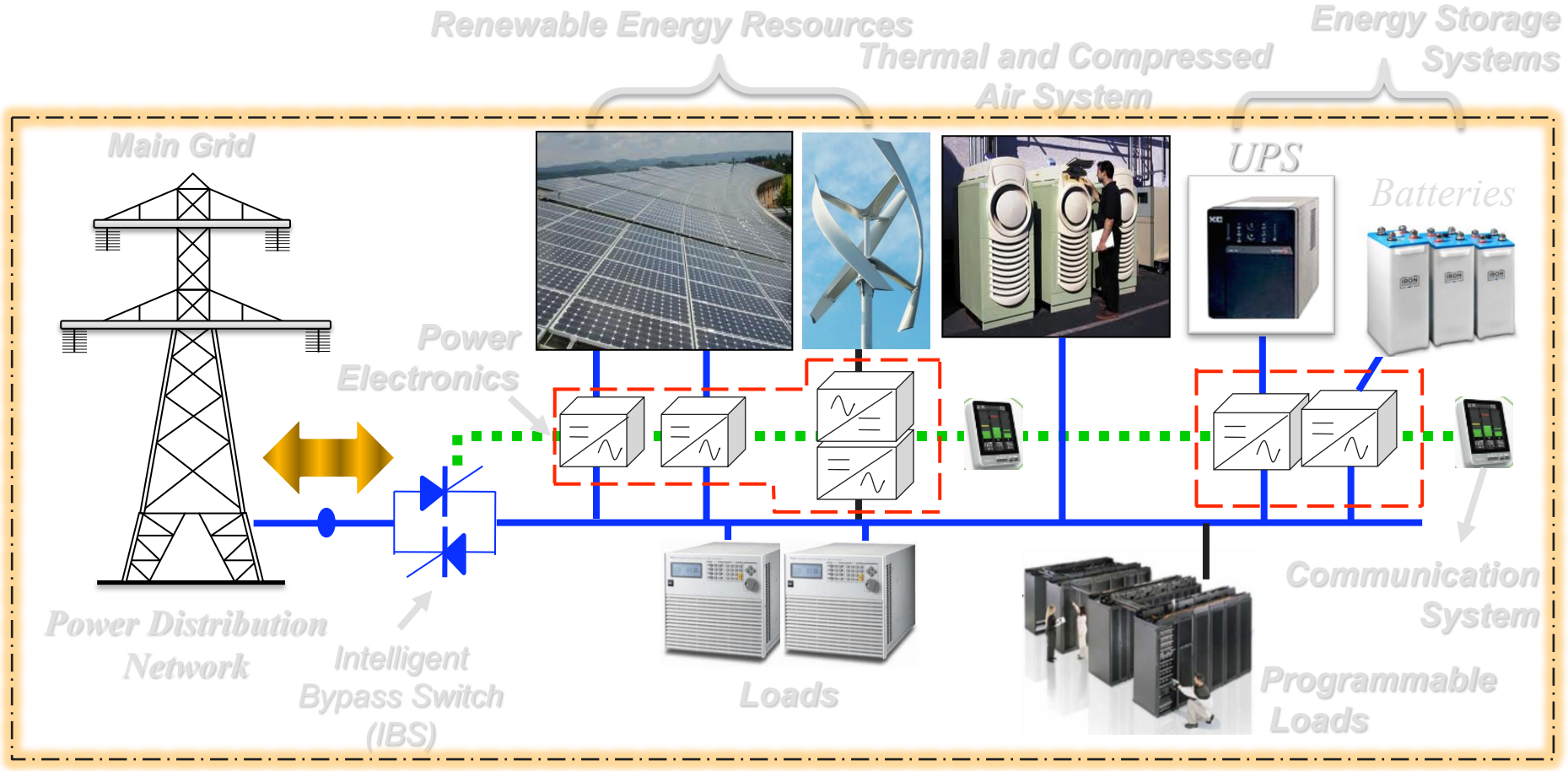


MicroGrids Activities

➢ *General aspects of a MicroGrid: "Definition and Operation"*

What is a Microgrid?

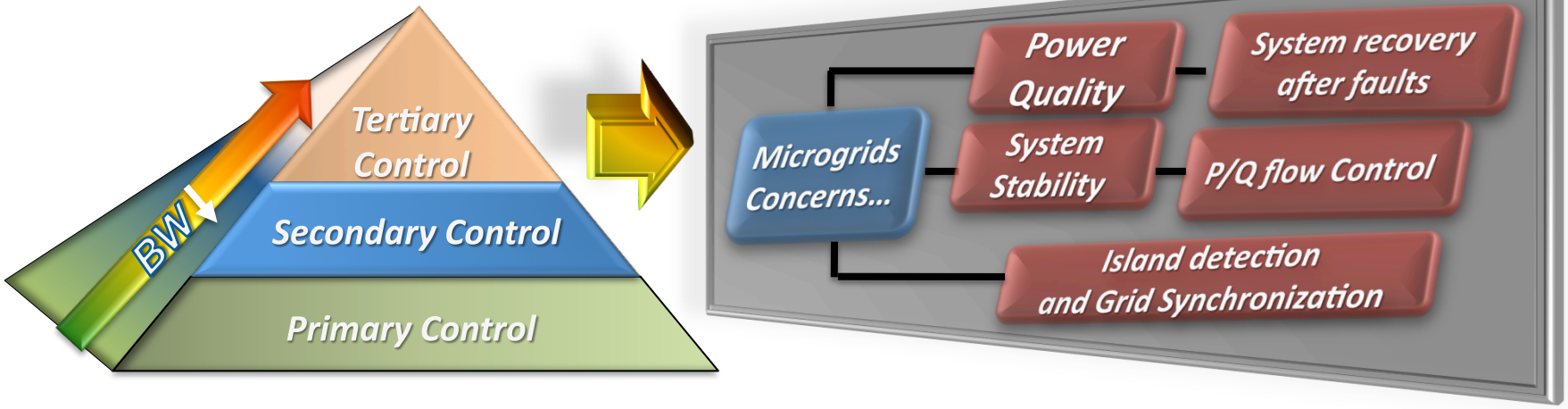


MicroGrids Activities

➢ General aspects of a MicroGrid: "Definition and Operation"

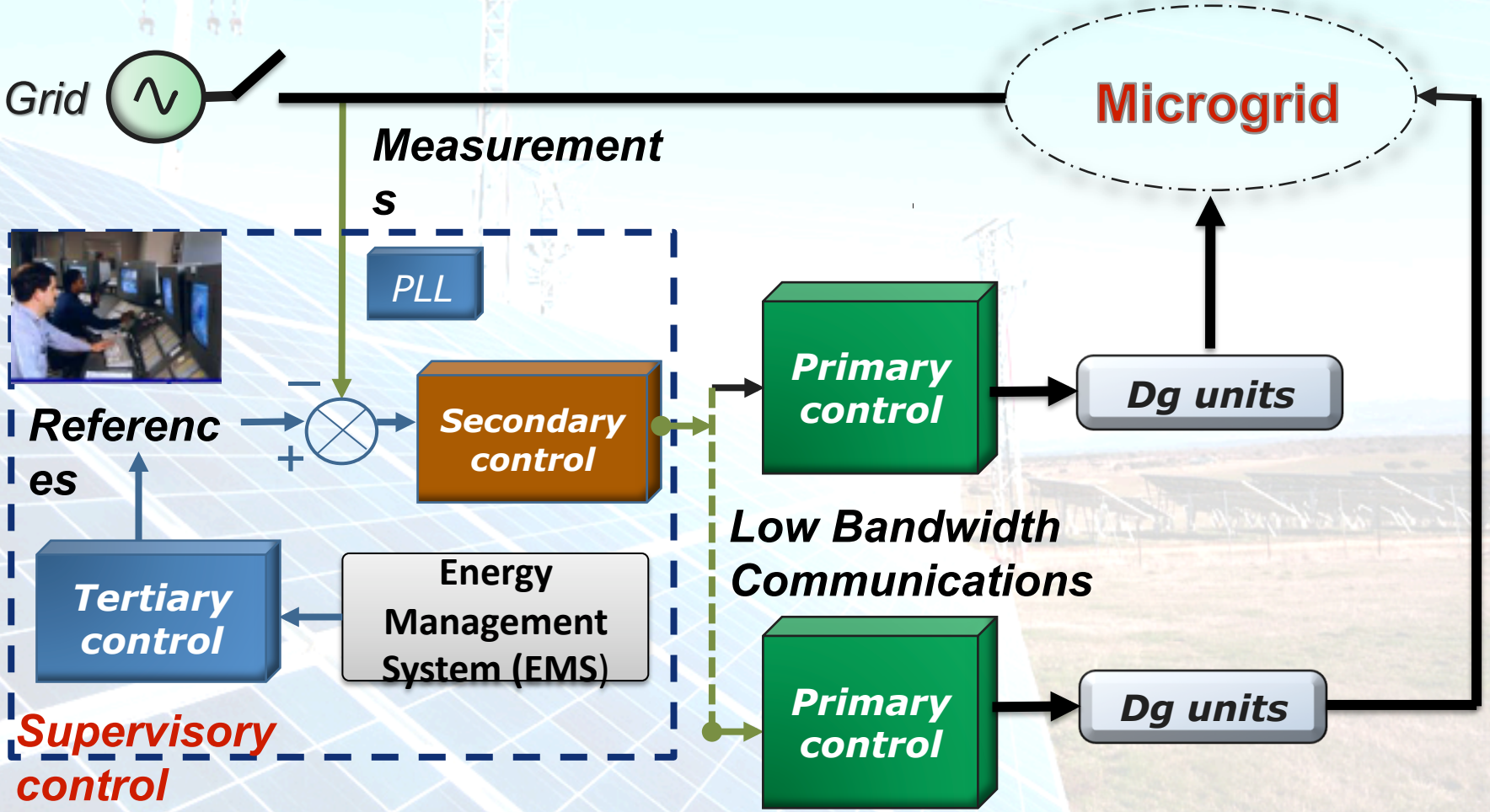
Hierarchical Control for MicroGrids

- **Primary Control: Modelling + Inner loops + droop Control (P/Q Sharing).**
- **Secondary Control:**
  - **f/V Restoration (Island) :** Set-points assignation from MGCC to the DGs .
  - **Synchronization (Island to grid Connected mode)**
- **Tertiary Control: Power Import/export from/to the grid.**



MicroGrids Research

MICROGRIDS: HIERARCHICAL CONTROL



MicroGrids Team in Aalborg University

Staff members:

- **Josep Guerrero, Professor**
- **Juan Vasquez, Ass. Prof.**

Post Doc 1
- **Tomislav**

DC MicroGrids
Energy storage

Post Doc 2
- **Fen Tang**

Wind-Powered MicroGrids

PhD 1
- **Lexuan Meng**

Tertiary Control
EMS Optimization

PhD 2
- **Qobad**

Secondary Control
Networked Control

PhD 3
- **Wu Dan**

Primary Control
Power Quality

PhD 4
- **Chendan Li**

Communications
Agents

PhD 5
- **Erum**

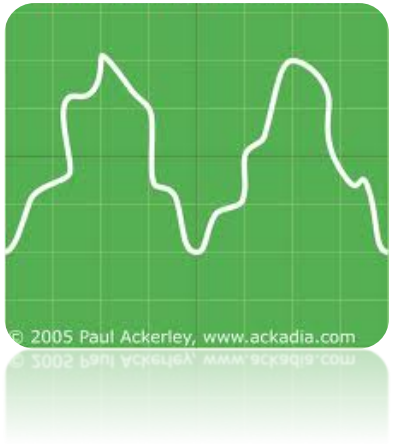
Protections
SCADA system

PhD 6
- **Solangi**

Energy Policy for MicroGrids

➢ *Issues in a Microgrid*

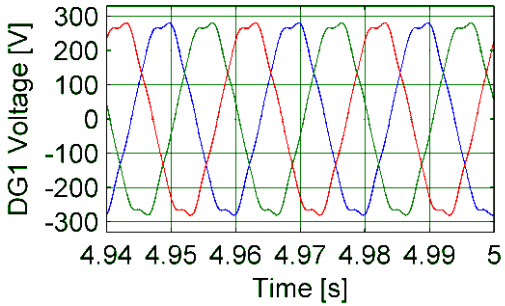
Problem: Harmonics in Microgrids



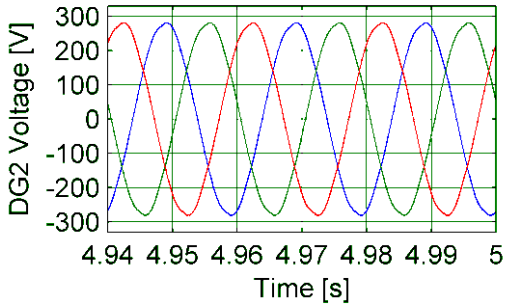
Possible solutions:

- *Microgrids needs to supply nonlinear currents (Ancillary Services)*
- *One DG unit could give more harmonics than another. (harmonic current sharing)*
- *Voltage Harmonic Reduction (Control strategies for HC)*

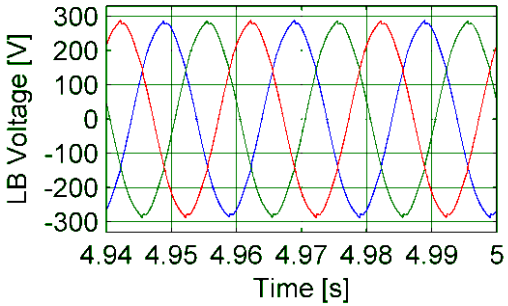
DG_1



DG_2

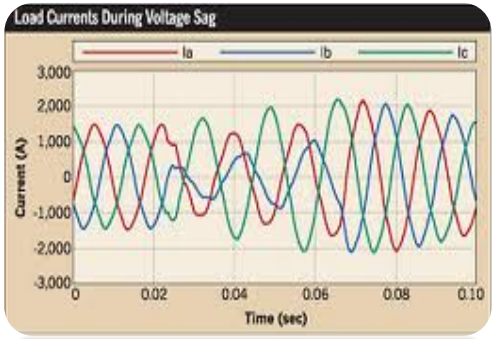


PCC



➢ *Issues in a Microgrid*

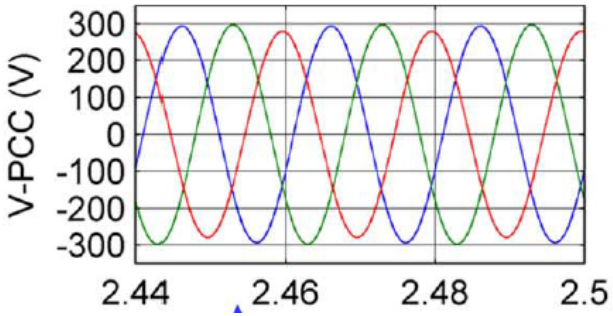
Problem: Unbalances in Microgrids

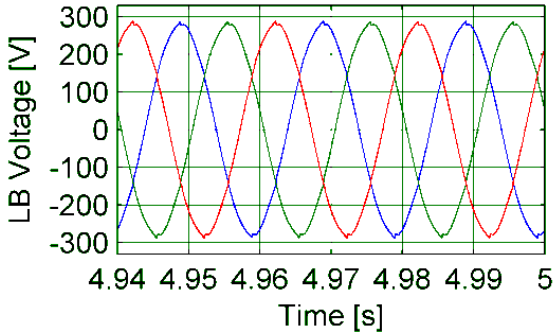


Possible solutions:

- *By means of sec. control, PCC voltage unbalances can be compensated by control signals to the primary level.*
- *PCC voltage data and the control signal are transmitted to/from secondary level through low bandwidth communication links.*
- *Voltage Unbalance Compensation (Control strategies)*

PCC Before UC



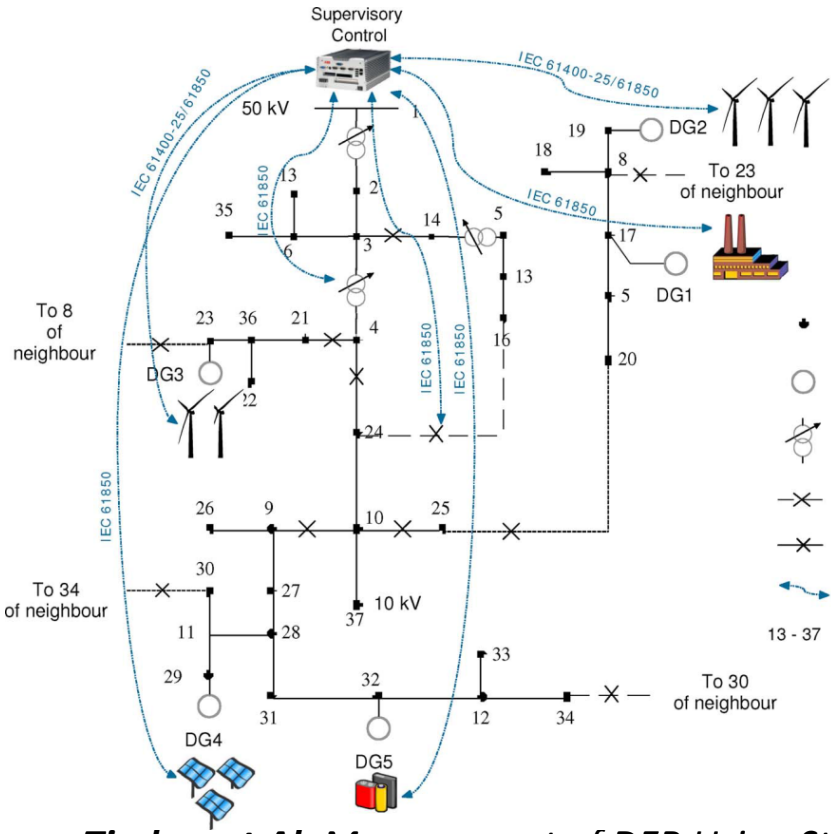


PCC After UC

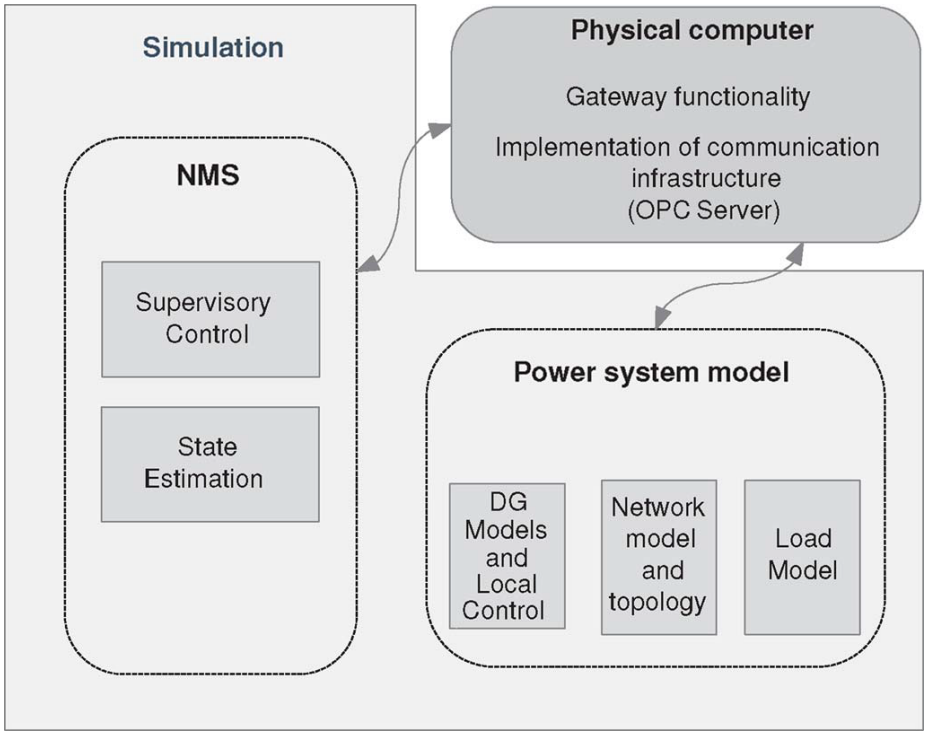
➢ *Issues in a Microgrid*

Communications

IEEE 37-bus model



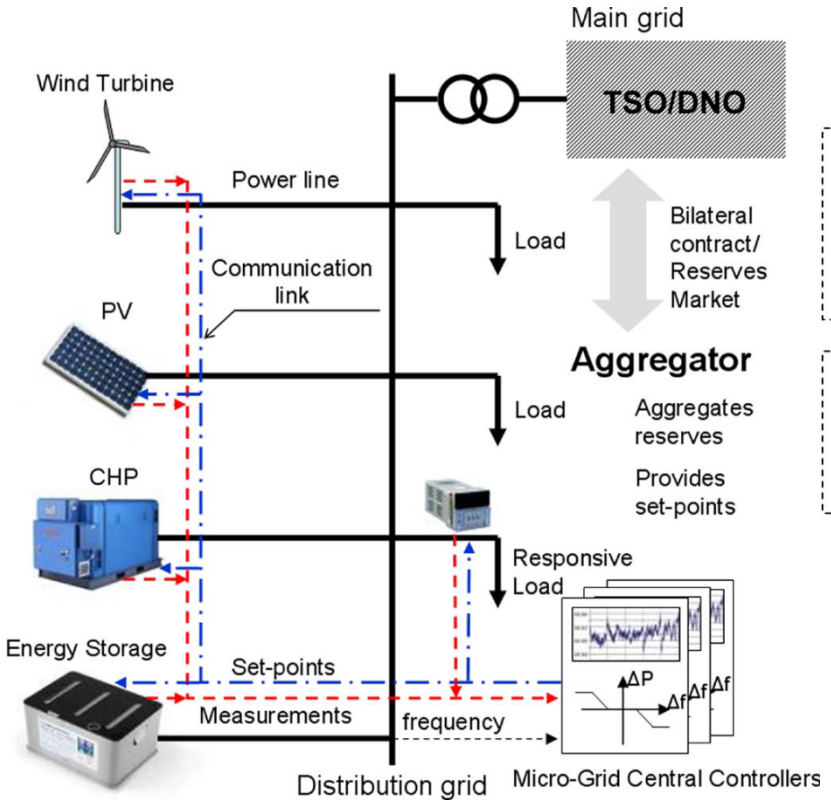
The gateway computer contains: communication model provided by IEC 61850 & IEC 61400-25 to describe the physical devices in the network model.



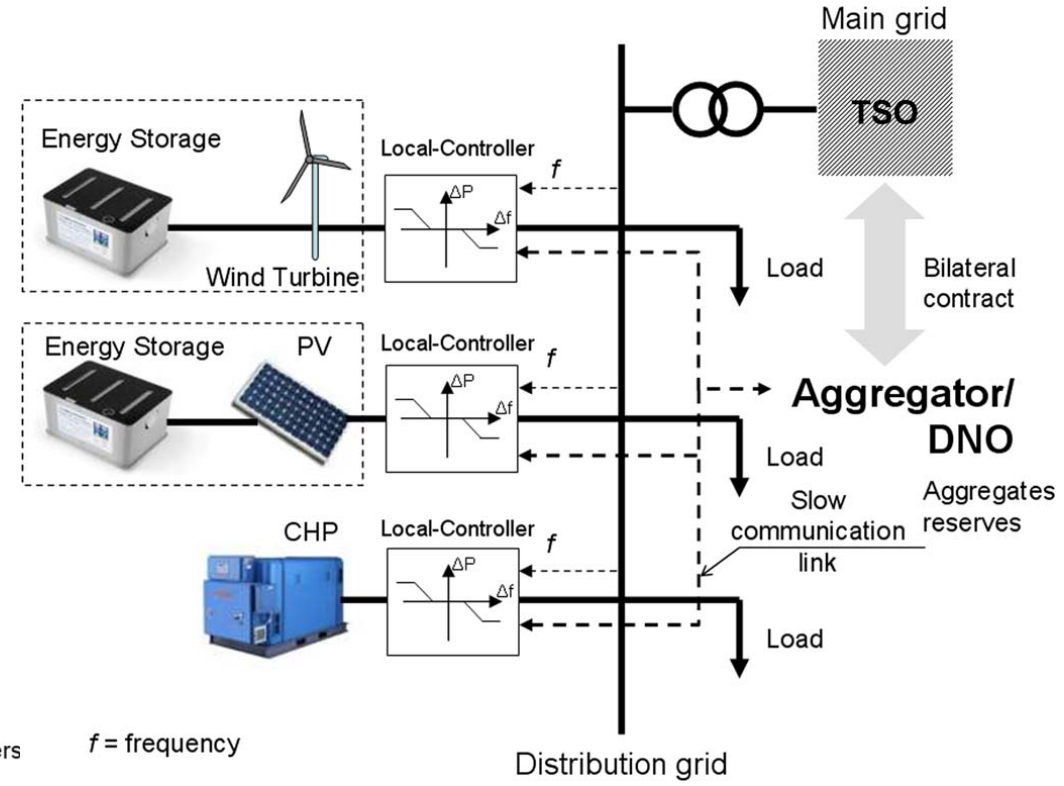
Timbus et Al. *Management of DER Using Standarized Communications and modern Technologies*

➢ *Distribution network with multiple MG setup*

Centralized Control

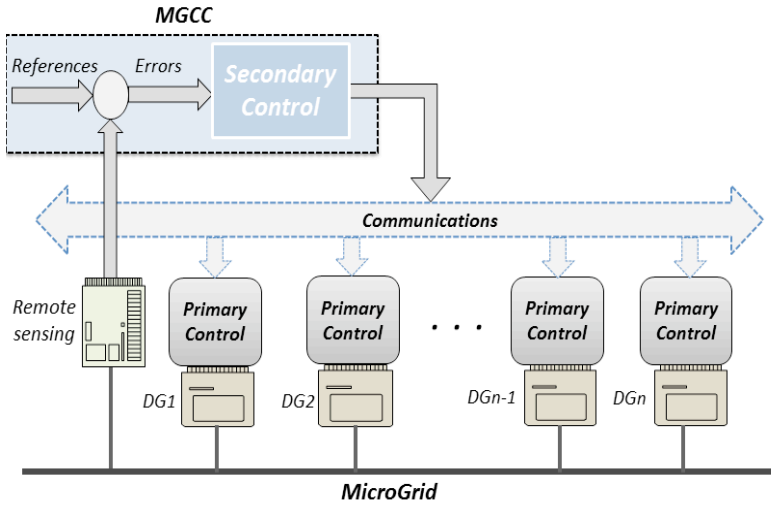


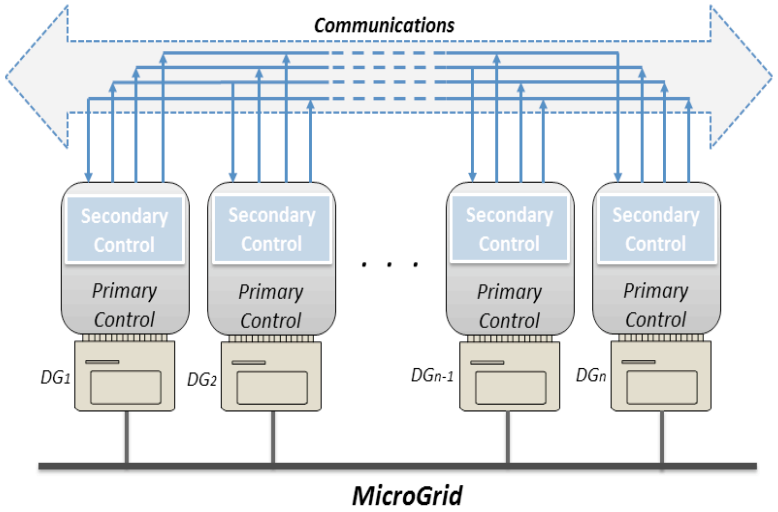
Distributed control

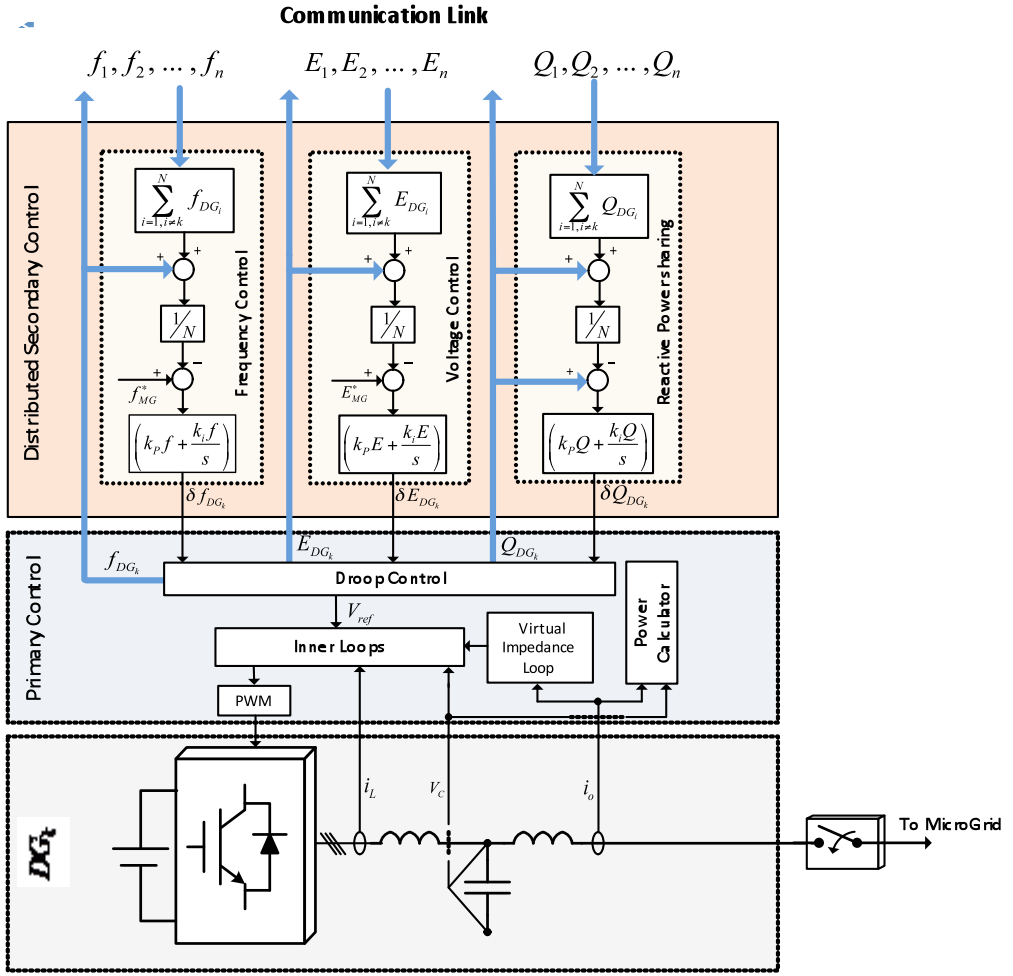


MicroGrids Research

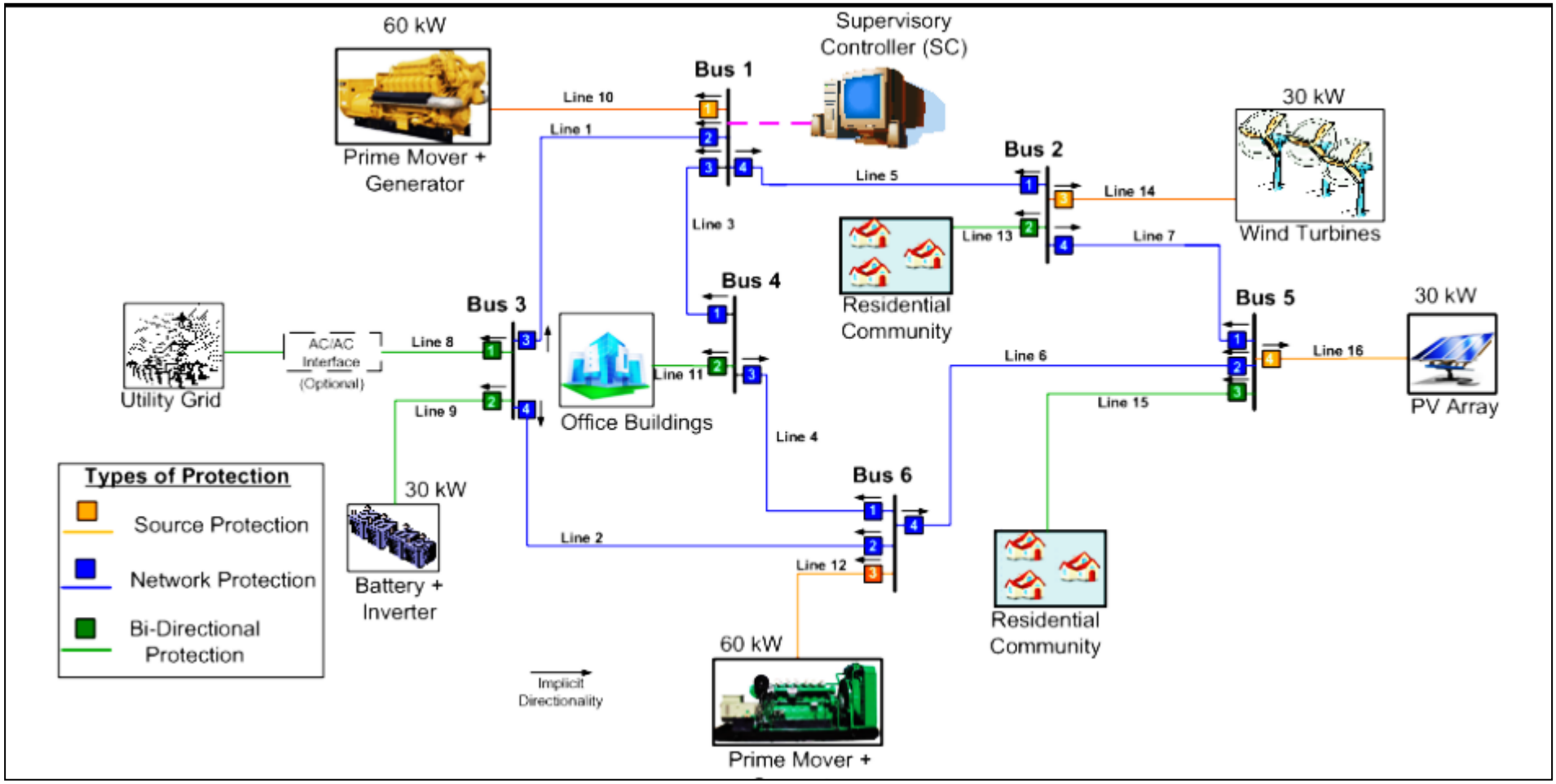
Networked Control Systems







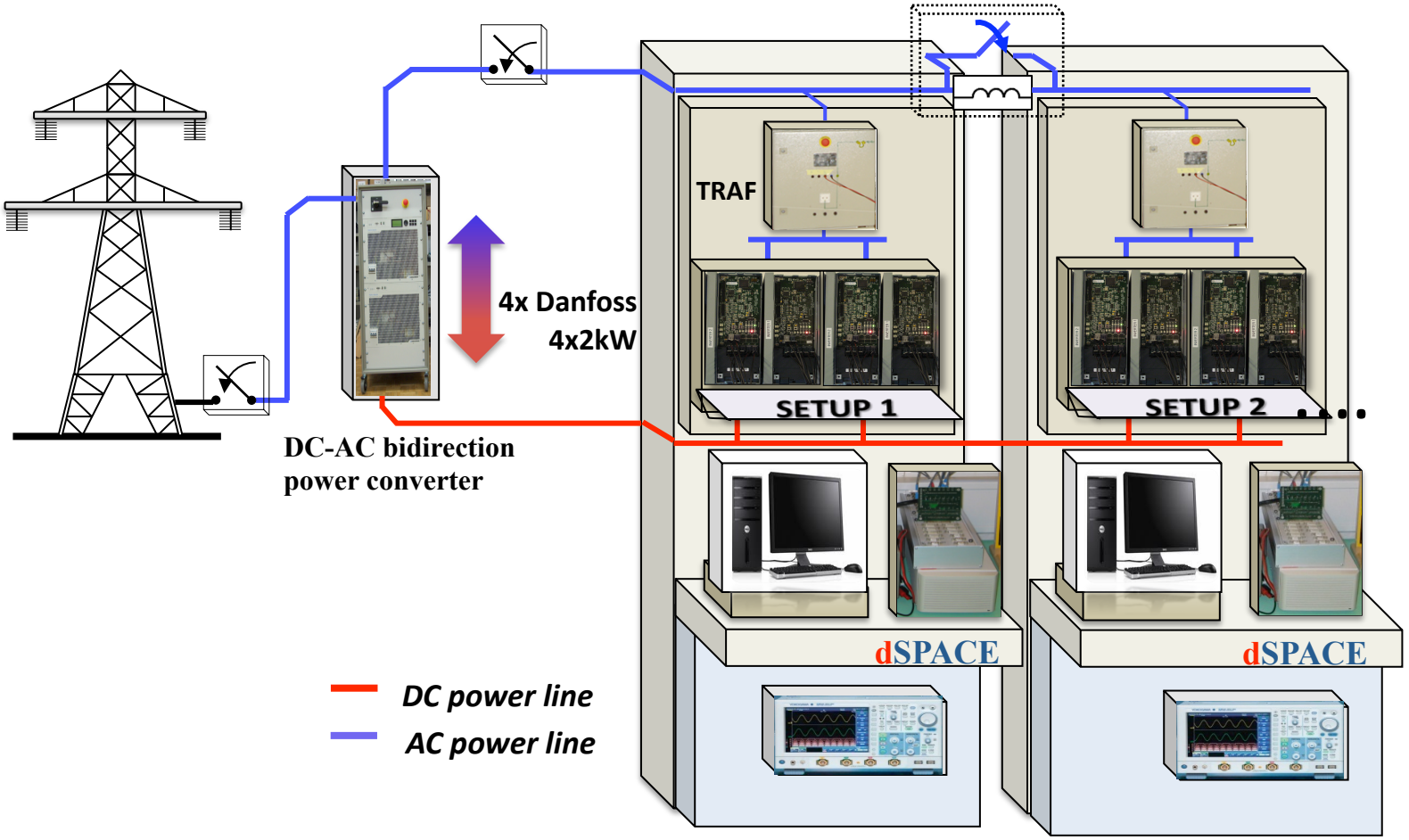
➢ Protections



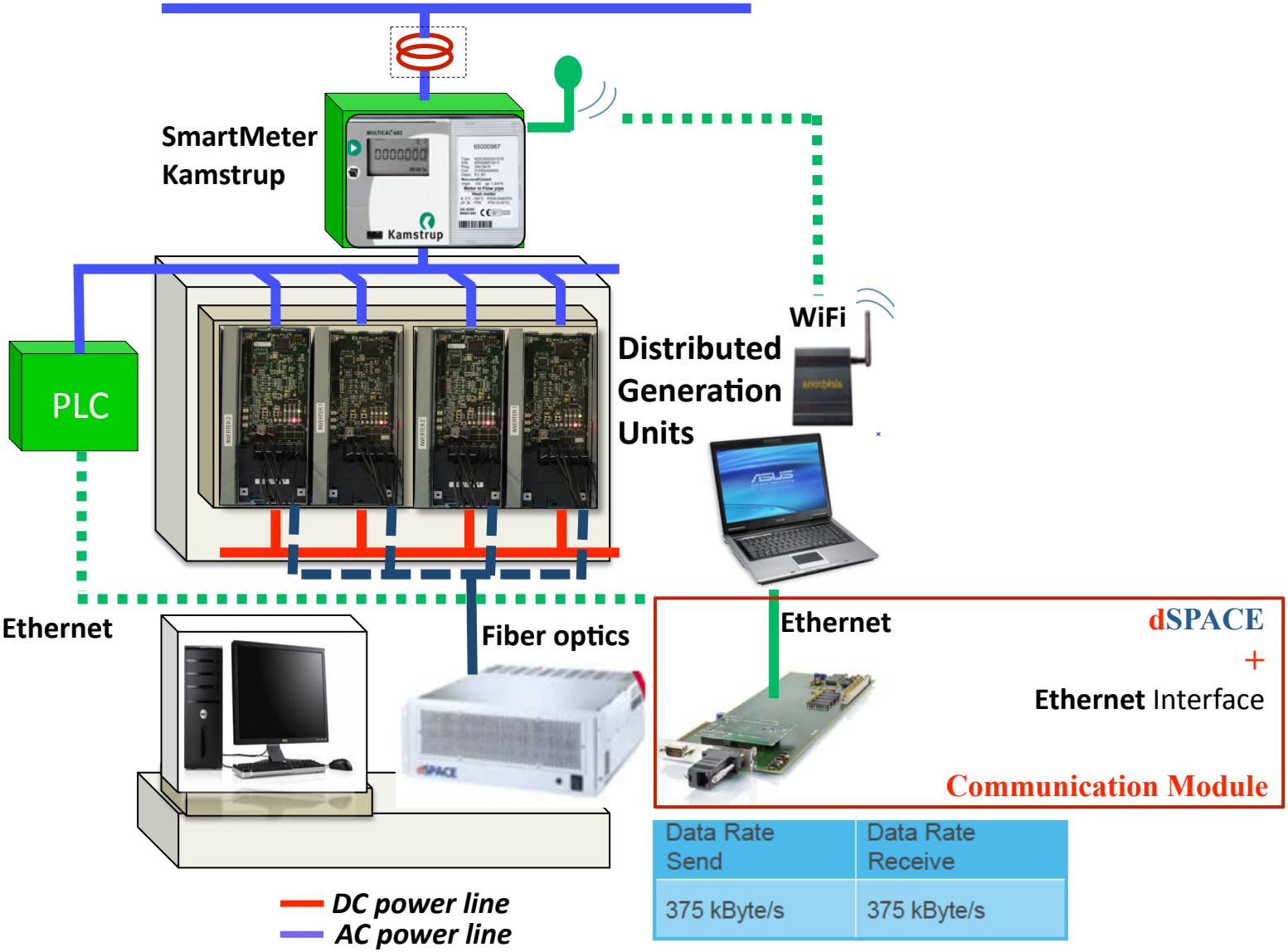
Architecture of the MicroGrid with four different zones of protection where all the breakers in a given bus is involved in bus protection.

- *Flexible MicroGrid*

iMG Laboratory - DOF

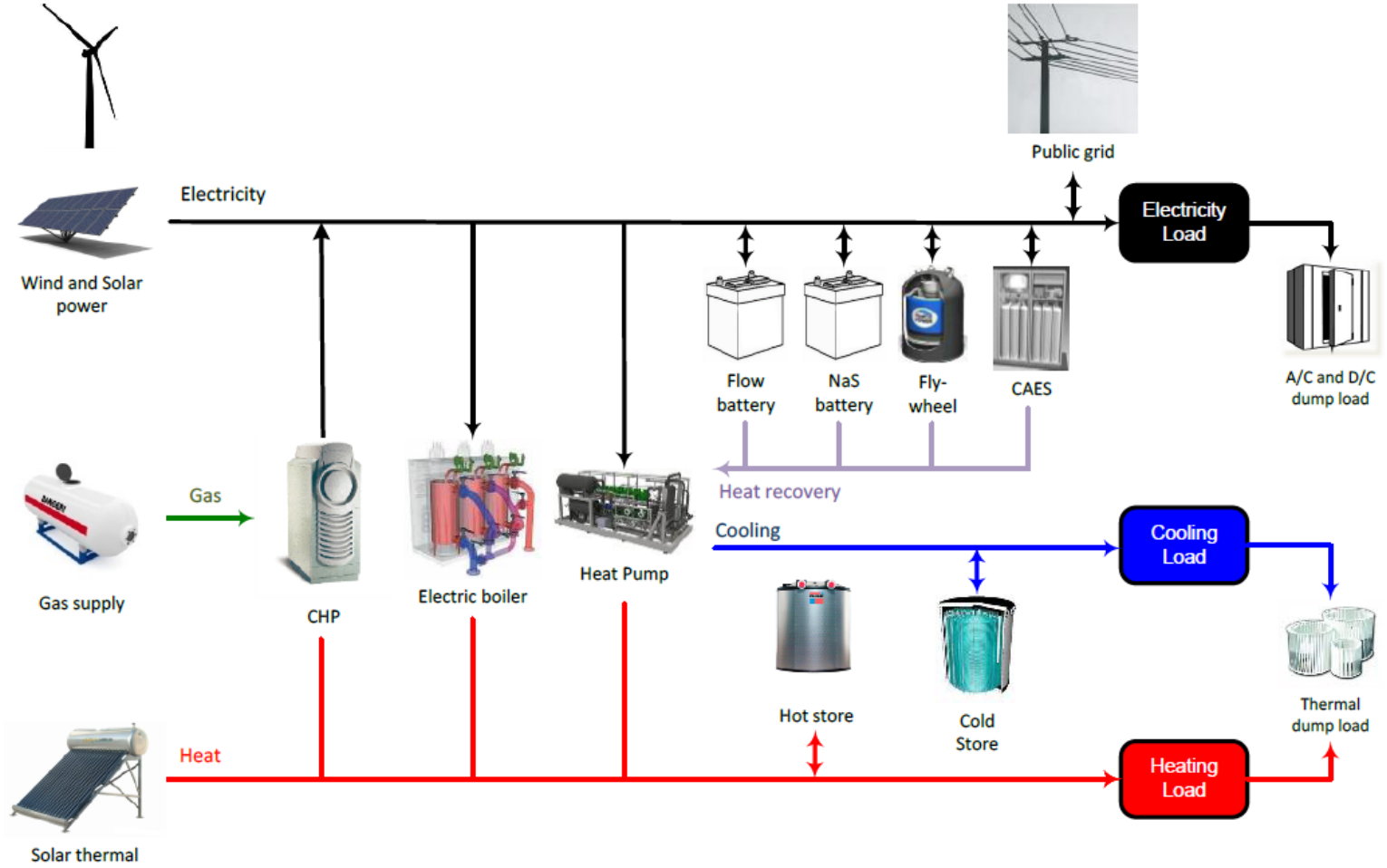


Case Study DES-ET AAU



Data Rate Send	Data Rate Receive
375 kByte/s	375 kByte/s

➢ *Electrical/heat MicroGrid*



MicroGrids Labs

MicroGridsDK Project – GreenlabsDK

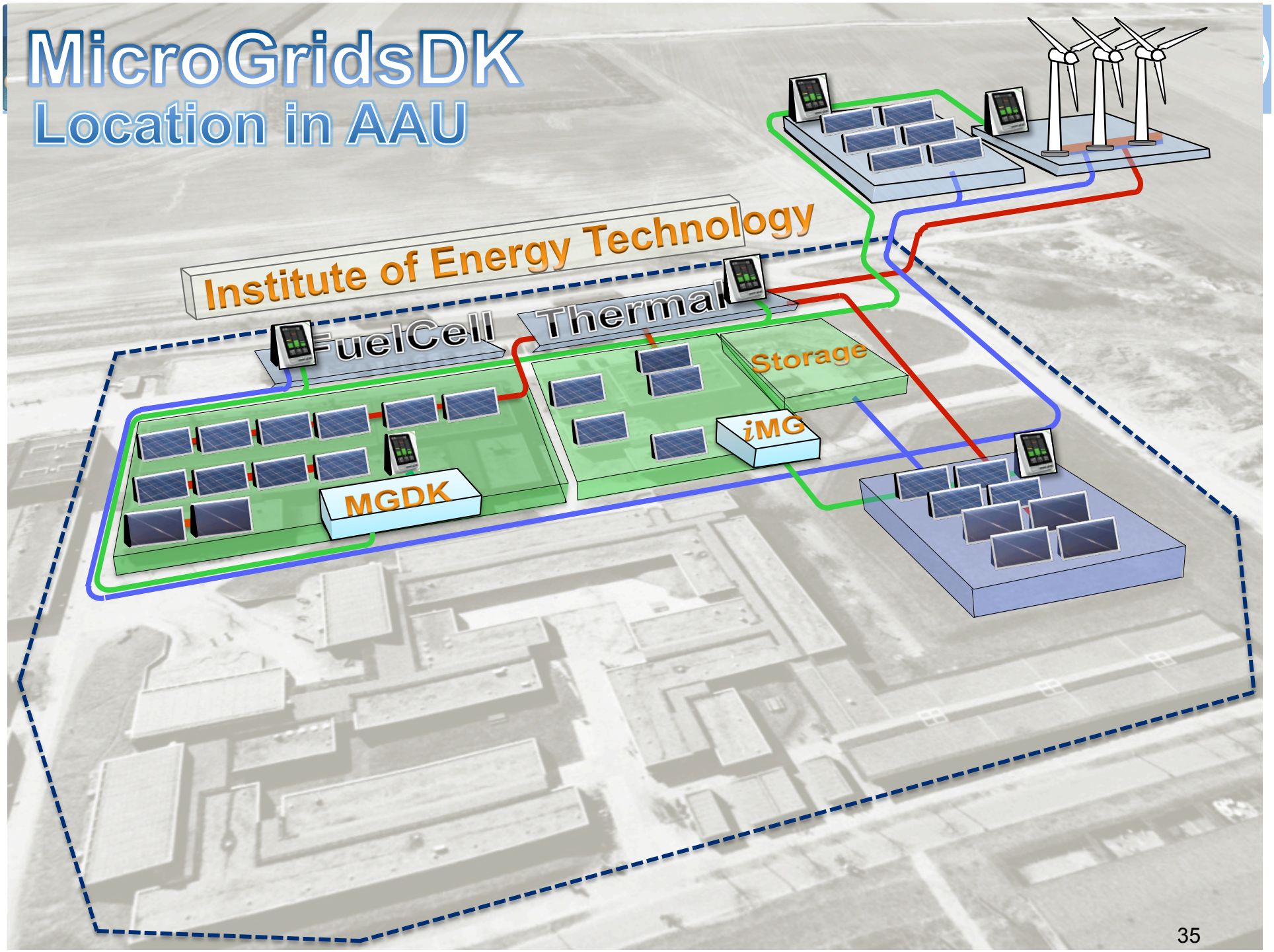
Generation	150kW
Storage	320kW
Total	470kW

Cooling/Heat dump
Electric Boiler
Heat Pumps
Compressed Air
Thermal Storage Unit
Heat Recovery
3kW
42kW
21kW
Utility Main Grid
Level 2: MicroGridsDK Facility
Vertical - 75kW
3-Blade 30kW
Solar PV 30kW
Gas Supply
Gas Turbine 2x30kW
End-Use Appliances
SmartMeters
HAN
MGDK Central Controller
EMS
Internet (Remote Access)
Zigbee
x6 150kW
AC Microgrid
DC Microgrid (400V-600V)
Qbeak Electric Vehicle
Level 1: iMG Laboratory
380V - 400Vdc
600 Vdc
RTDS Technologies
FC 50kW
Flywheel 60kW
FlowBattery 10kW
Programmable Loads
R = 40kW
L = 50kVAr
C = 10kVAr
SMES 200kW
Batteries Ni-Salt
DC Microgrid
AC Microgrid

ero joz@et.aau.dk

Protections Thermal Communication

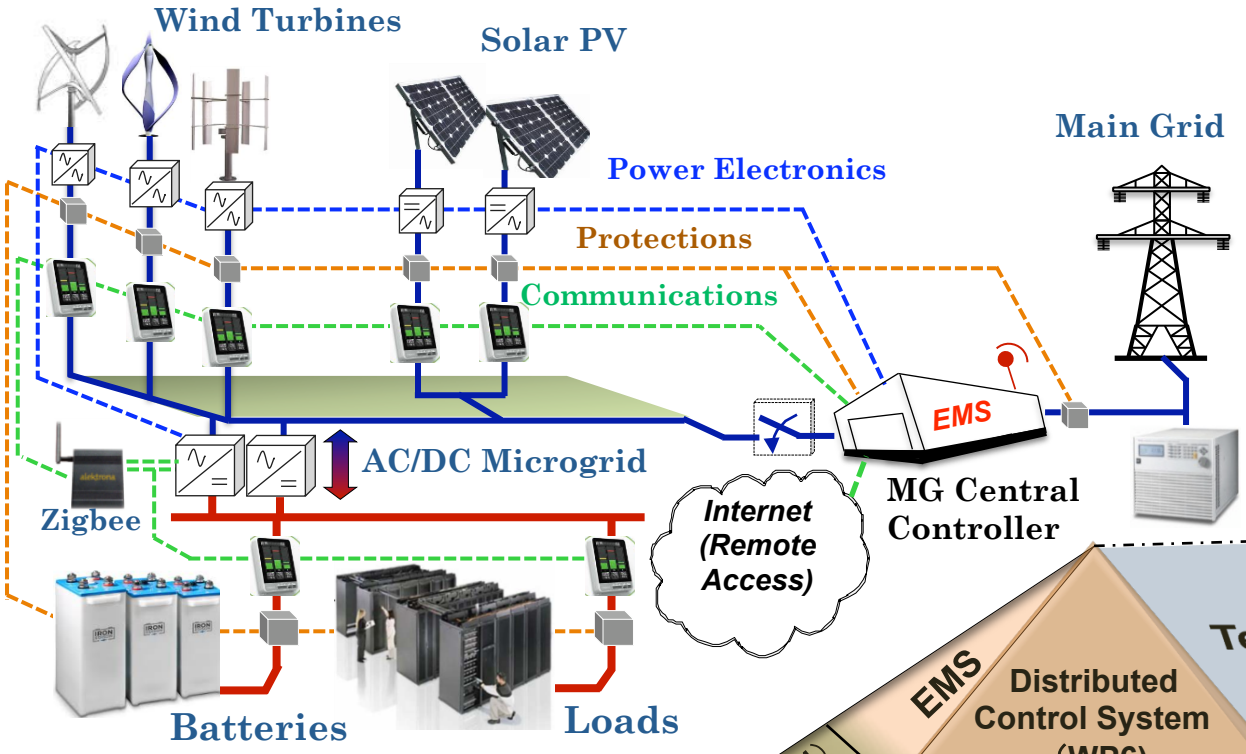
MicroGridsDK
Location in AAU



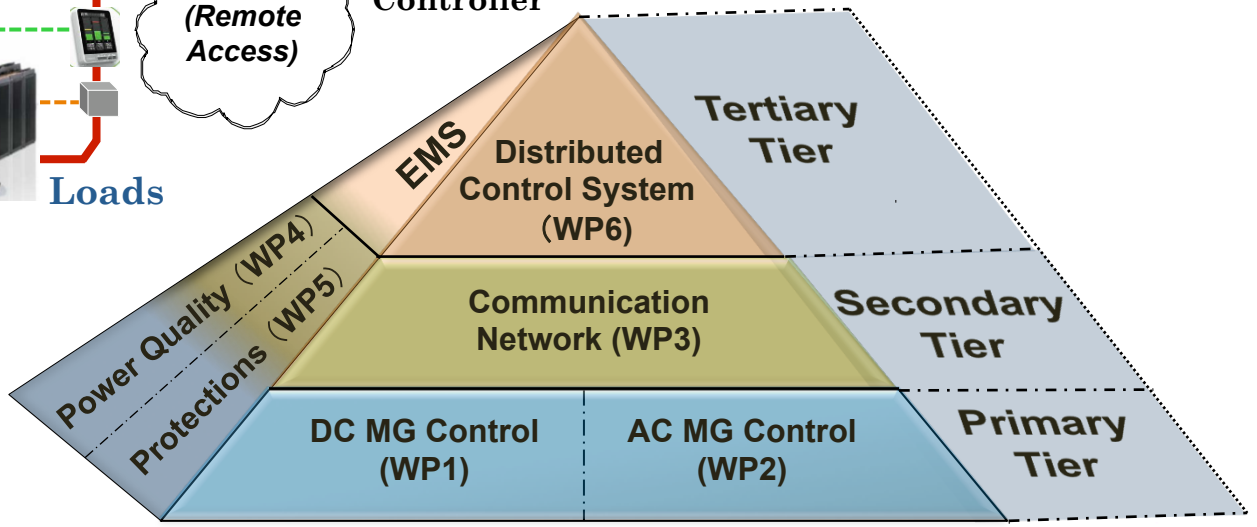
MicroGrids Projects

➢ *Project*

Networked Control Systems



Network Control Architecture



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MicroGrids Activities

- ***Publications in MGs (July 2011 – 2012)***

  10 IEEE TIE / TPEL Journal Papers

  10 IEEE Conference papers

  AE: IEEE TPE, TIE, IEM

- ***3 Tutorial in MicroGrids***
- ***2 Special Issue in Microgrids.***

- ***Collaborations with Companies***

Jema | innovative energy

Distributed Control of an Intelligent Microgrid Plant **(Vasque country – Spain)**

The MicroGrid to be implemented will have an installed generation power of 300 kW and will be composed of a generators and loads system that will be able to operate connected to the electric distribution network or in isolated way. Integration of Power line communication, distributed generators, electrical vehicle integration, Wi-Fi (MESH network).

MicroGrids Activities

➢ *MicroGrid Courses*

Remus Teodorescu received the Dipl.Ing. degree in electrical engineering from Polytechnical University of Bucharest, Romania in 1989, and PhD. degree in power electronics from University of Galati, Romania, in 1994. In 1998, he joined Aalborg University, Department of Energy Technology, power electronics section where he currently works as a professor He has more than 180 papers published, 1 book ("Grid Converters for Photovoltaic and Wind Power Systems", ISBN-10: 0-470-05751-3 – Wiley) and 4 patents. He is an IEEE Fellow Member, Past Associate Editor for IEEE Trans on Power Electronics and chair of IEEE Danish joint IES/PELS/IAS chapter.
He is the founder and coordinator of the Green Power Laboratory at Aalborg University focusing on the development and testing of grid converters for renewable energy systems. He is the coordinator of Vestas Power Program, involving 10 PhD students and guest professors in the areas of power electronics, power systems and energy storage. His areas of interests are: design and control of power converters used in photovoltaics and wind power systems, grid integration with wind power, medium-voltage converters, HVDC/FACTS, energy storage energy systems.

Josep M. Guerrero received the B.S. degree in telecommunications engineering, the M.S. degree in electronics engineering, and the Ph.D. degree in power electronics, in 1997, 2000, and 2003, from the Technical University of Catalonia, Barcelona, Spain. He is an Associate Professor at the same university, where he teaches courses on digital signal processing, control theory, and renewable energy systems. Since 2011, he has been a Full Professor on MicroGrids at the Department of Energy Technology, Aalborg University. His research interests include distributed and hierarchical control of AC and DC MicroGrids.
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Tamas Kerekes obtained his Electrical Engineer diploma in 2002 from Technical University of Cluj, Romania, with specialization in Electric Drives and Robots. He received his MSc and PhD degree in 2005 and 2009, at Aalborg University. Currently he is working as an Assistant Professor at the same Department. His main interest is on PV inverter modelling, control and topologies as well as modulation techniques with focus on transformerless PV inverter systems.

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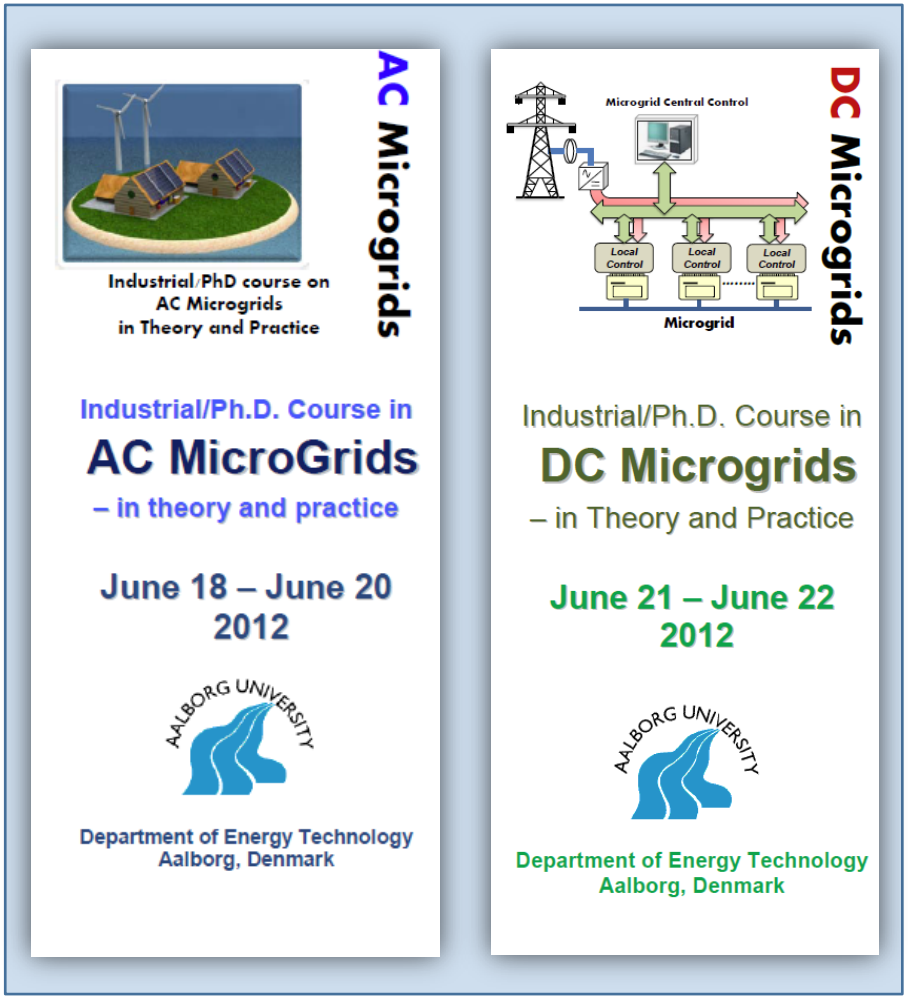
Fee

4000 DKK for PhD students/Academics outside of Denmark and 1500 DKK for PhD students in Denmark, who is not from AAU. 6.000 DKK for the Industry. If you also take the course DC MicroGrids and SuperGrids in the spring, there will be a discount. The prices for both courses will then be 6000 DKK for PhD students Academics outside of Denmark and 2000 DKK for PhD students in Denmark, who is not from AAU. 9.000 DKK for the Industry. The fee includes coffee, lunch for all days and copy of slides and simulation models on a USB key.



MicroGrids Activities

➢ *MicroGrid Courses*

Remus Teodorescu received the Dipl.Ing. degree in electrical engineering from Polytechnical University of Bucharest, Romania in 1989, and PhD. degree in power electronics from University of Galati, Romania, in 1994. In 1998, he joined Aalborg University, Department of Energy Technology, power electronics section where he currently works as a professor He has more than 180 papers published, 1 book ("Grid Converters for Photovoltaic and Wind Power Systems", ISBN-10: 0-470-05751-3 – Wiley) and 4 patents. He is an IEEE Fellow Member, Past Associate Editor for IEEE Trans on Power Electronics and chair of IEEE Danish joint IES/PELS/IAS chapter.
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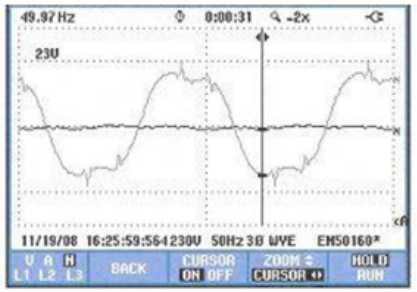
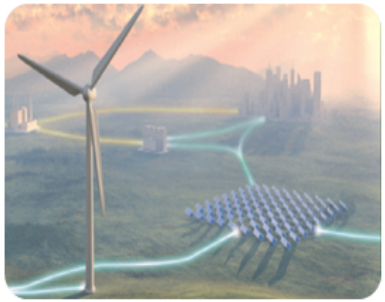


Industrial/Ph.D. Course
Power Quality in Microgrids
in Theory and Practice
Nov. 26 – Nov. 27 2012

AALBORG UNIVERSITY

Department of Energy Technology
Aalborg - Denmark



Industrial/Ph.D. Course in
Communications for Microgrids
- in Theory and Practice

Nov. 28 – Nov. 29 2012

AALBORG UNIVERSITY

Department of Energy Technology
Aalborg - Denmark

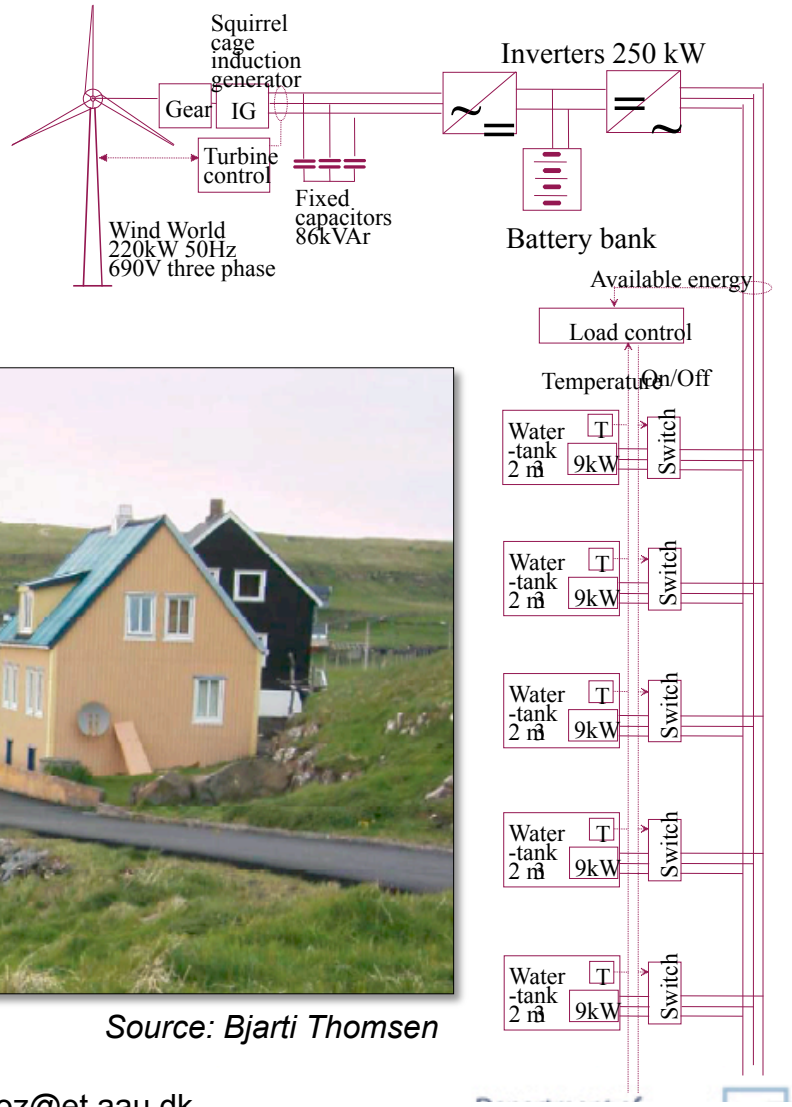
Outline

1. Denmark – a paradigm of decentralized electrical energy system
2. MicroGrid Research in Aalborg University
3. **Faroe Islands Wind Powered MicroGrid Project**

Faroe Islands MicroGrid

Average wind speed ~ 9.4 m/s
WT 220 kW
Generation 950 MWh per year

Source: Bjarti Thomsen



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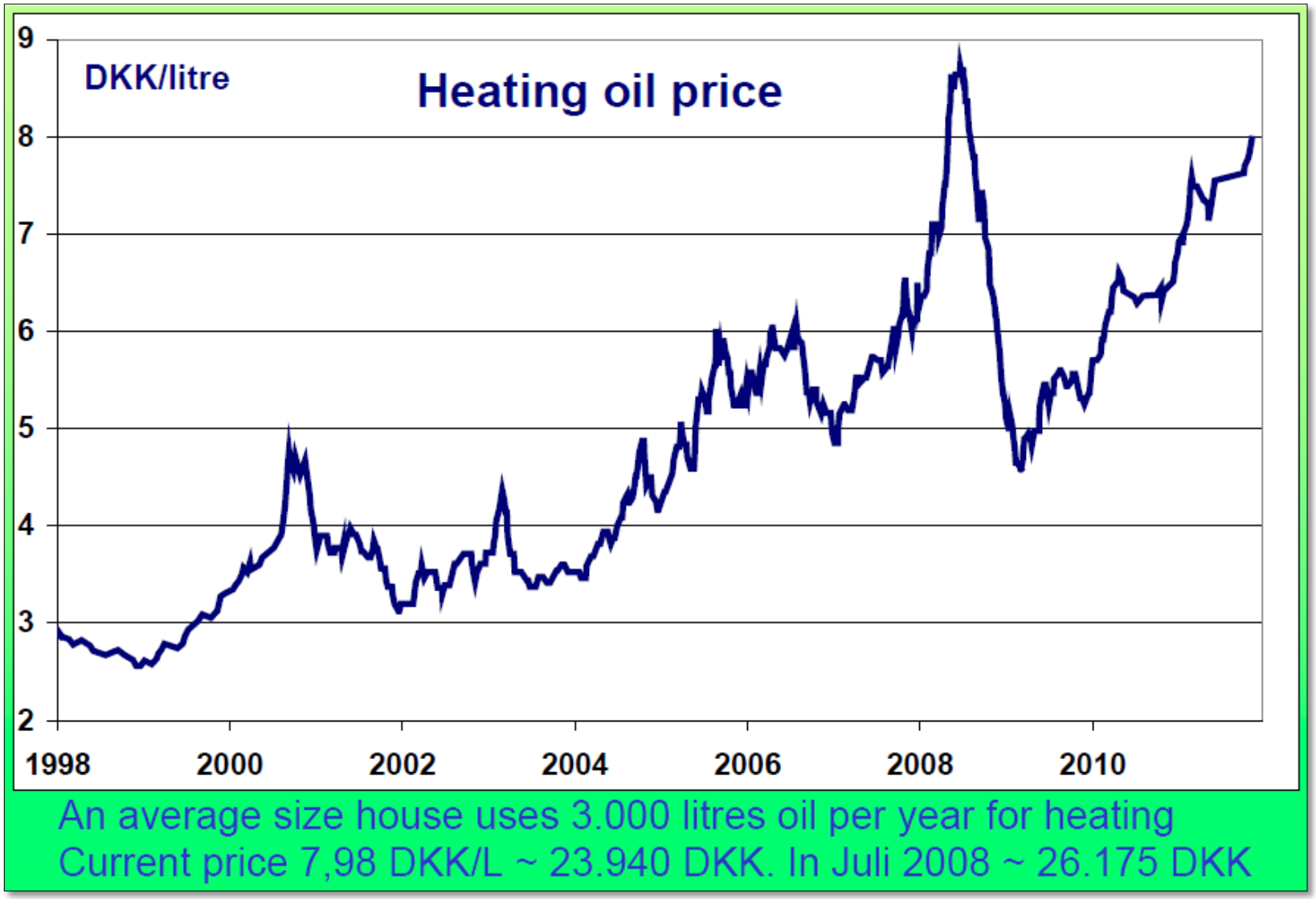
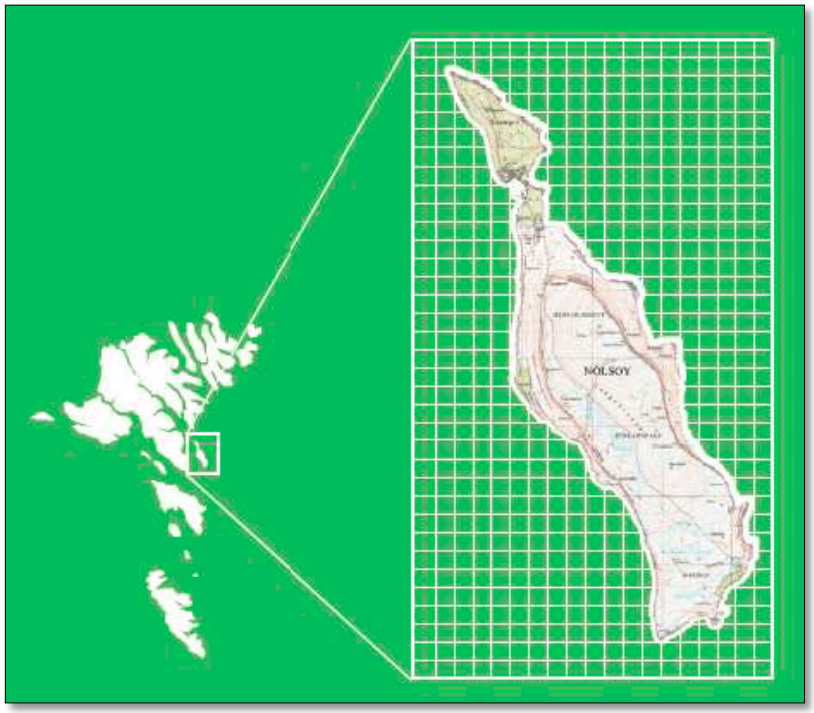
Faroe Islands MicroGrid

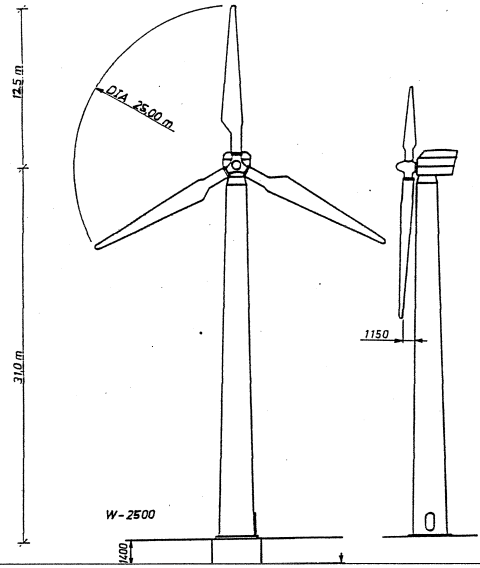


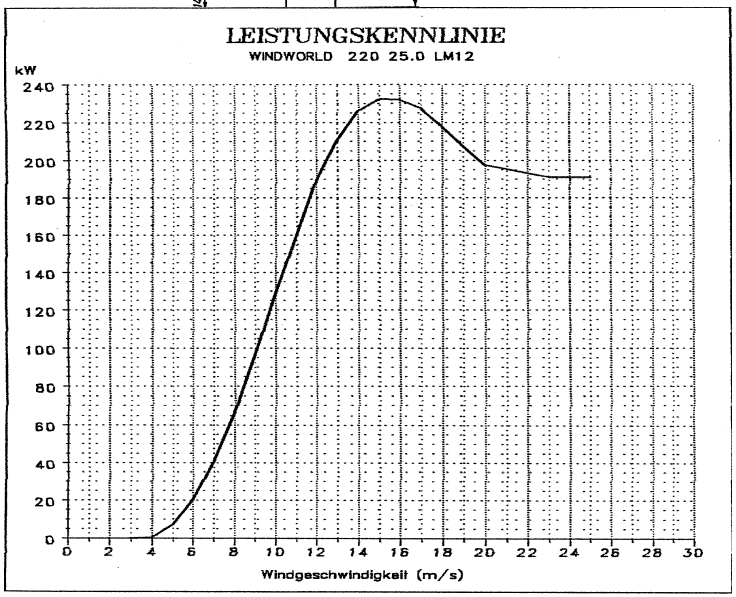
Source: Bjarti Thomsen

Faroe Islands MicroGrid

Faroe Islands
The island of Nólsoy







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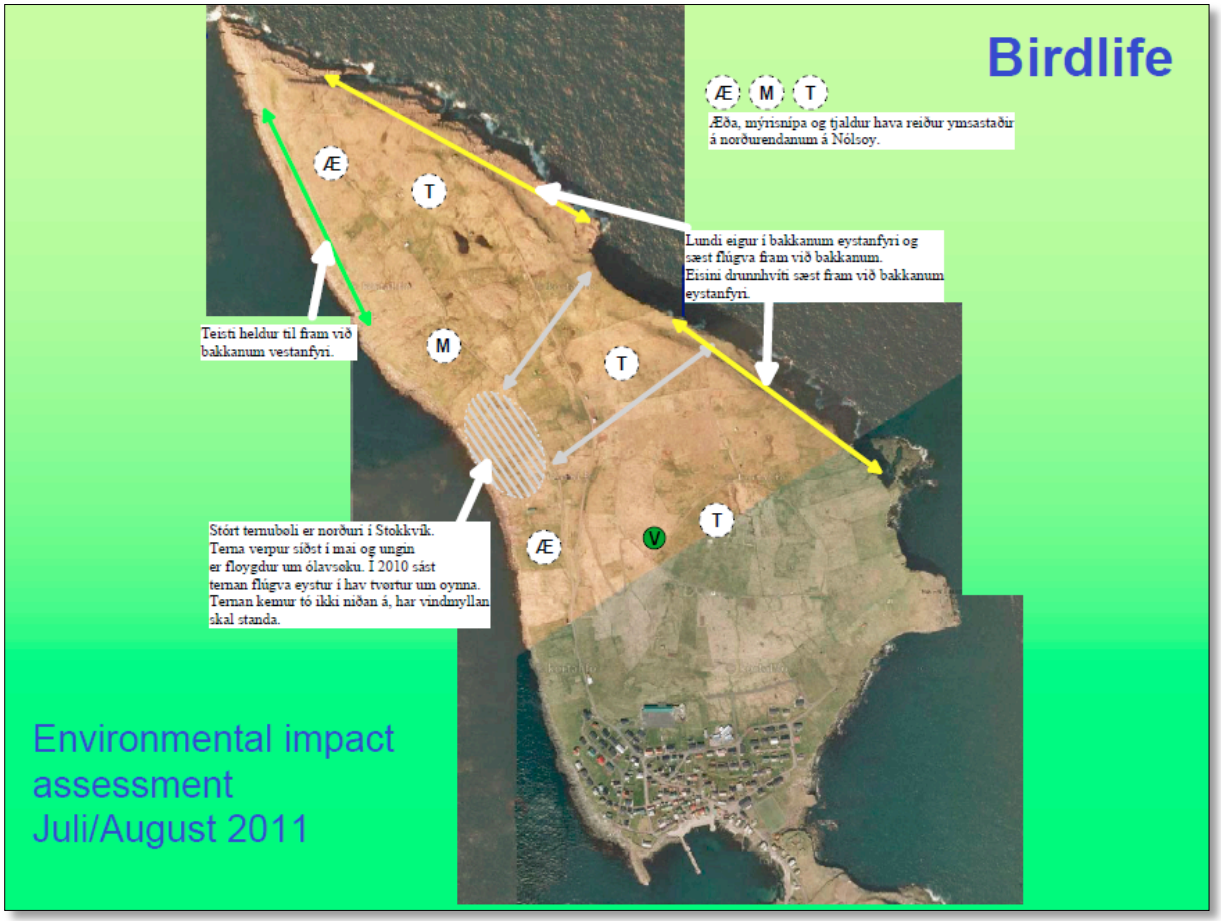
Faroe Islands MicroGrid



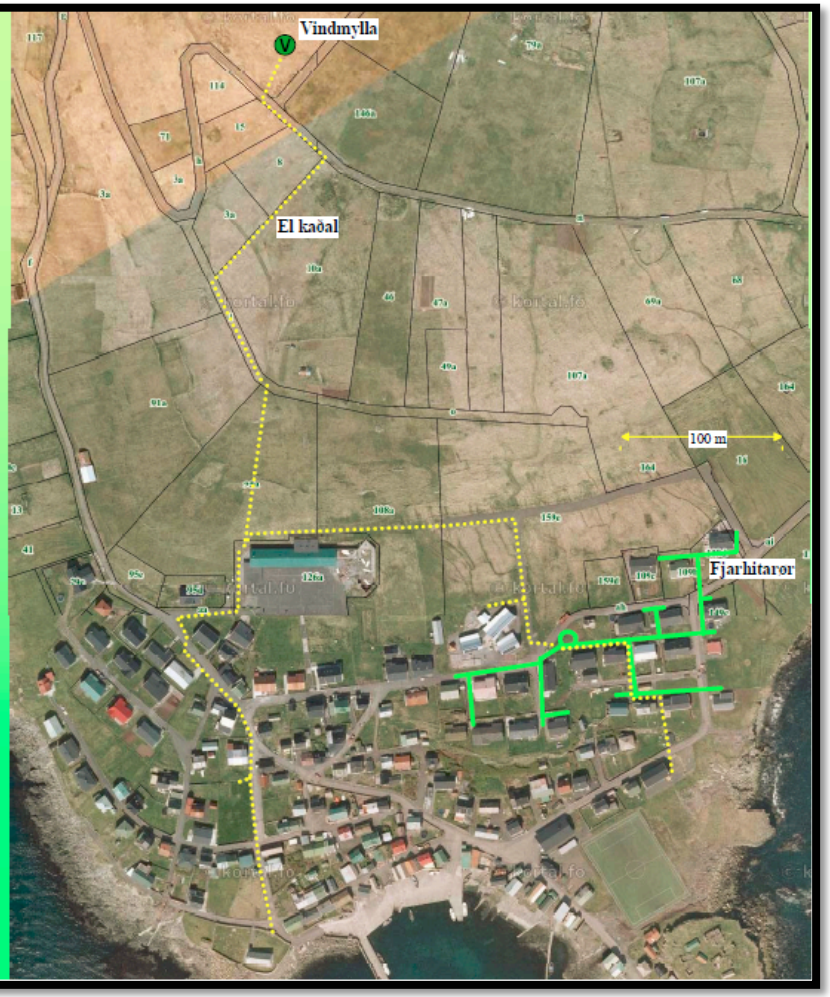
Source: Bjarti Thomsen

Faroe Islands MicroGrid

Source: Bjarti Thomsen

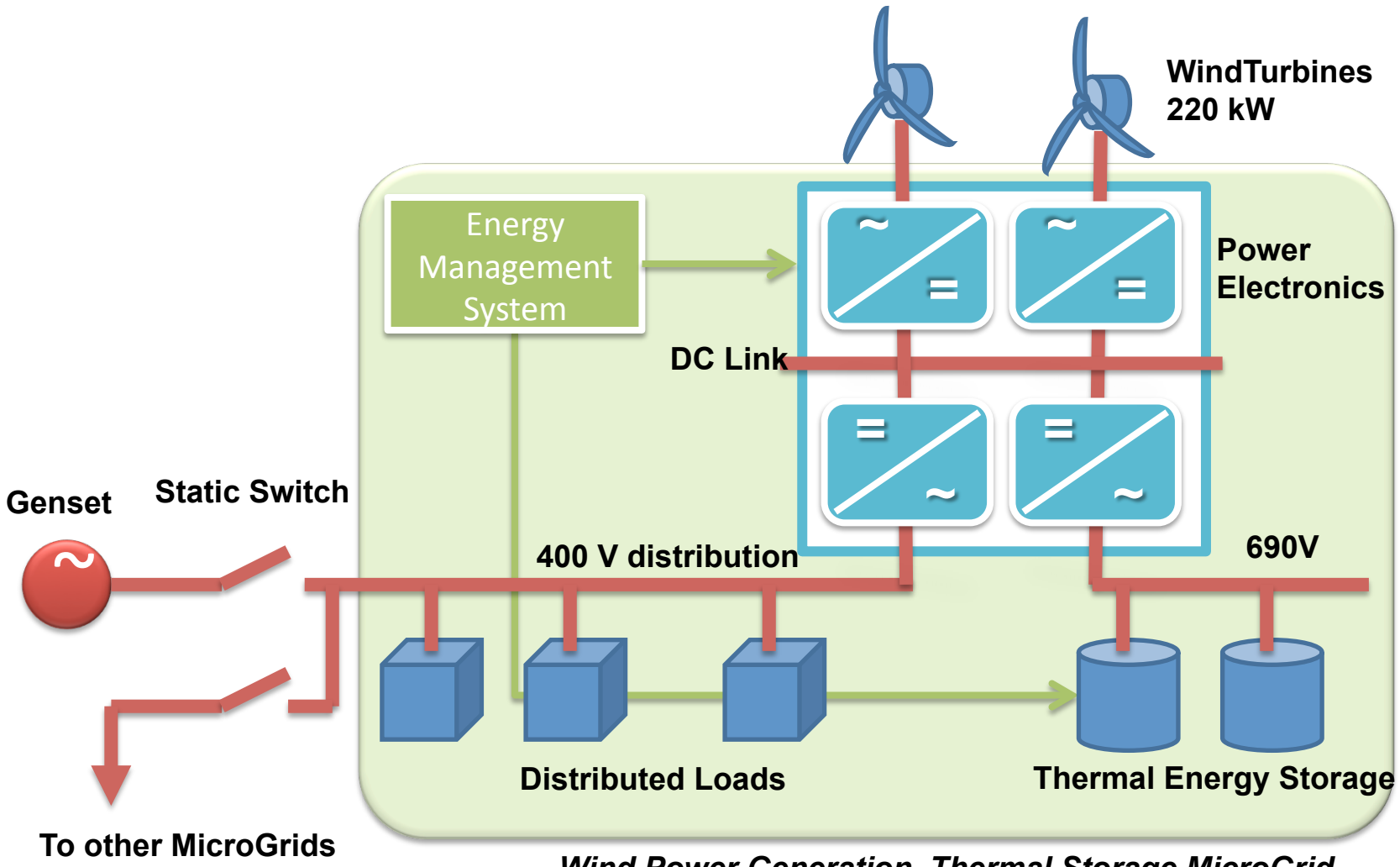
Faroe Islands MicroGrid

System
(cables, pipes)



Source: Bjarti Thomsen

Faroe Islands MicroGrid



Wind Power Generation, Thermal Storage MicroGrid

Thank you for your attention!

For cooperation or further information, please contact us:

joz@et.aau.dk

Microgrids research program

AALBORG UNIVERSITY