Overview of Microgrids in Europe

Developments in system operation and research and test facilities

Niagara 2016 Symposium on Microgrids
20-21 October 2016
Niagara-on-the-Lake, Ontario, Canada

Presenter: Wolfram Heckmann, Fraunhofer IWES, Kassel, Germany

Overview of Microgrids in Europe

- **Developments in system operation**
  - Web-of-Cells – approach of the Electra project
  - Remote areas
  - Continuity of supply
- **Research and test facilities**
  - DERlab
  - Summary of projects and facilities of DERlab members in Europe

- Annex
  - Detailed description of microgrid projects and test facilities of DERlab members

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Web-of-Cells – Approach of the Electra project

© electra Turn-On the Grid of the Future

Web-of-Cells Concept

EERA
Smart Grids Joint Programme

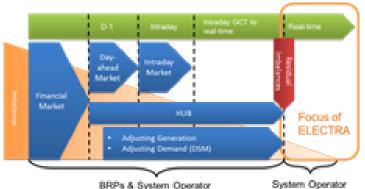1. **Decentralized control scheme** for future reserves activations based on local observables : **solving local problems locally**

2. Load Frequency Control Areas ➔ smaller *cells* that are responsible both **detecting the need** for reserves activations as well as for the reserves **activation itself**

3. **Local collaboration** between cells based on local observables instead of global collaboration based on frequency as global observable

CIRED Side Event
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Web-of-Cells – Approach of the Electra project

Trends and Challenges

- From: Transmission grid connected dispatchable synchronous generators with downstream power distribution ('copper plate')

  To: Large number of small intermittent generators that are distributed everywhere (all voltage levels)

- Increasing electrical loads (at medium/low voltage levels)

- Active control of flexible loads

  ⟹ Reverse powerflows, local congestions, local voltage problems
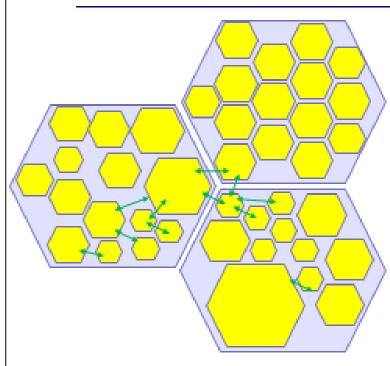
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Web-of-Cells – Approach of the Electra project

Web-of-Cells Concept

➤ Solve local problems locally based on local observables, acknowledging that:
  ➤ Causes are highly distributed and local
  ➤ Resources that can solve are local
  ➤ Detailed local information is needed to active securely and effectively
➤ **Instead of** : Bottom-up / computation challenge / top-down

➤ Voltage : obvious
➤ System Balance : restore as aggregated effect of restoring local balances
  ➤ Local balance as in 'L = G'
  ➤ Local balance as in 'adhere to your import/export profile' (cfr FRC) : tie-line powerflows : responsibilizing, 'the polluter pays'
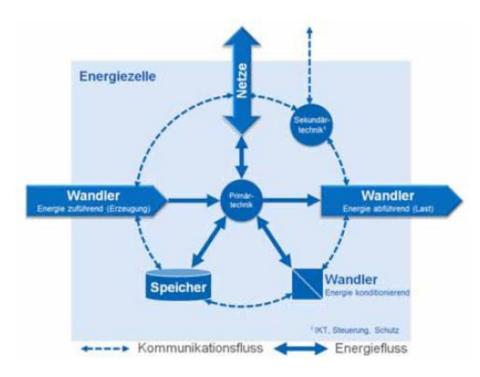
➤ Divide-and-conquer : computational tractability and communication/aggregation complexity and cost

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ELECTRA side event at CIRED 2016, June 15th, Helsinki
Chris Caerts
http://www.electrairp.eu/index.php

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Web-of-Cells – National adaptation

- VDE-ETG study „Der Zellulare Ansatz" („Cellular Approach")
  - Combined cells of information, power, and heat
  - New options for system operation
    - Provision of ancillary services
    - Temporarily self-sustaining operation
      (especially for residential, commercial, and small industrial areas)
  - Summing-up of cells horizontally and vertically
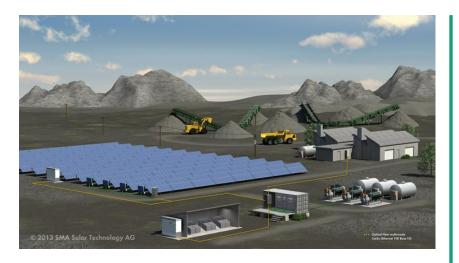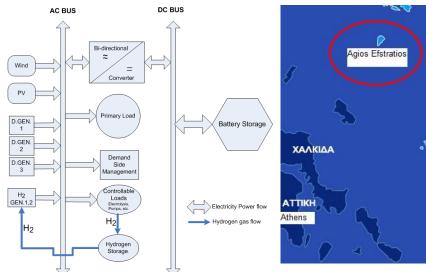 - Island operation in emergencies

[VDE-ETG 2015]

Remote areas - Project examples from Germany and Greece

- **Off-grid industrial sites**

© 2013 SMA Solar Technology AG

- **PV-Diesel-Battery systems up to some MW for off-grid applications**

- https://www.solarstromforschung.de/pv-diesel/

- **Geographic islands**

- **Agios Efstratios RES Electrification system including H2**

- aiming at 100% RES and not less than 85% of the annual demand

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Continuity of supply – Contribution from microgrids

■ **Objectives and benefits of microgrids**

  ■ to serve particularly sensitive loads such as emergency service

  ■ to use local assets difficult to operate by the centralized grid

  ■ to present a controlled profile to the wider power system

… the intent is that a microgrid can function for more than a few minutes as a controlled electrical island.

➔ Supply critical infrastructures/ emergency centers   [CIGRE 2015]

➔ Bridge the black-out after a break down until the system is restored

➔ Use of defined and stable loads, e.g. for network restoration procedures

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Continuity of supply – Supply islands in cities

- **Civil protection in long-lasting black-outs, i.e. days to weeks**
  - Supply of the inhabitants by protection & security forces like fire brigade and technical services with mobile diesel gen-sets
  - Support of the protection & security forces by structures not relying on the connection to the transmission grid
  - First priority: safeguard vitally important services like water supply or emergency center

- **Building supply islands in German cities**
  - Coverage of municipal islands often about 50% of regular interconnected operation
  - Time to build-up the island network 2-6 hours (others sources 10-12 hours)

German short study on municipal energy supply during long-lasting black-outs

[Höser 2015]

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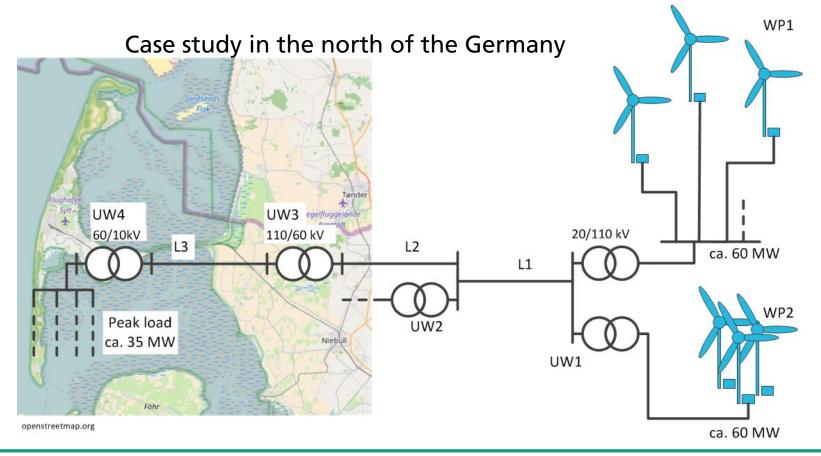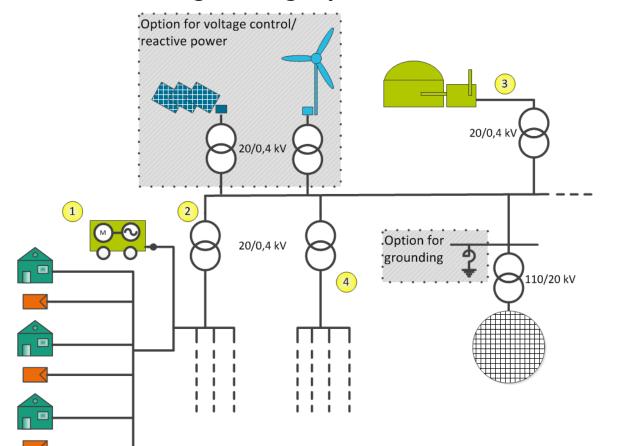
Continuity of supply – NETZ:KRAFT project "HV-island"

■ Feed-in grid with wind parks supplying a load center
   ■ Failure of the transmission system (380 kV)

Case study in the north of the Germany

Continuity of supply – NETZ:KRAFT project "MV-island"

■ PV and biomass to start islands from LV and extend to MV
  ■ Failure of the high voltage system (110 kV)

Concept

1) Start with mobile diesel gen-set, include PV
2) Extend to MV line
3) Activate biogas plant
4) Extend supply to further villages

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DERlab - European Distributed Energy Resources Laboratories e.V.

■ Over thirty institutes from Europe and U.S. performing research related to Smart Grids (SG) integration of Distributed Energy Resources (DER)

■ Accredited testing of DER-units and smart grid equipment

■ Support of smart grid development and integration of renewable energies

■ Organisation of information and knowledge exchange on testing infrastructure

■ Contribution to standardisation activities

■ The association's research laboratory infrastructure offer the necessary expertise and equipment for DER in a coordinated manner

DERlab

www.der-lab.net
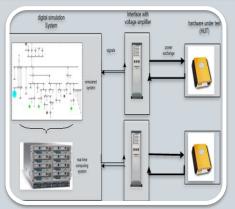
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DERlab - Methods and Techniques

Full scale testing of DER components

- Lab capabilities up to the MVA range, LV to HV
- Dedicated facilities for all RES technologies
- Compliance testing and validation of all grid relevant functions
- Performance, safety and reliability

Lab and field testing of DER systems

- Testing and validation of power system (ancillary) services from distributed units

Interoperability and communications

- Laboratory platforms able to test the interoperability between DER units
- Testing of communication interfaces according to international standards

Power and Controller Hardware in the Loop (PHIL/CHIL)

- Synthesis of simulation and hardware experiments
- Allows equipment to be validated in a virtual power system

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Projects and facilities of DERlab members in Europe

- **Microgrids Research Infrastructures**

  - **Small scale laboratory level:**
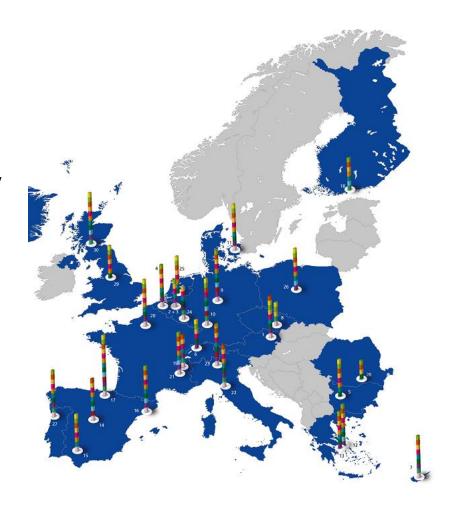
  MicroDERlab (RO), AIT (AT), LEMKO (BE), TUS-RDS (BG), HES-SO (CH), FOSS (CY), KIT (DE), SEER (ES), TECNALIA (ES), VTT (FI), G2Elab (FR), RSE (IT), DNV GL(NL), TU Lodz (PL), Uni. Manchester (GB) and INESC Porto (PT).

  - **Large scale laboratory level:**

  Fraunhofer IWES, DTU (DK), CIEMAT (ES), Uni. Sevilia (ES), NTUA (GR), CEA-INES (FR) and Uni. Strathclyde (GB).

  - **Demo site level:**
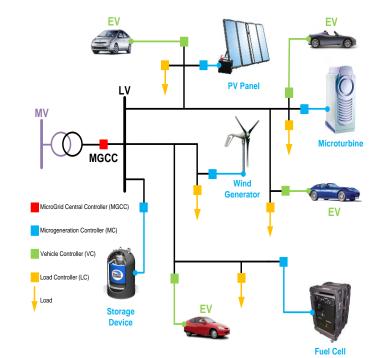
  EDF – Concept Grid –France and CRES – Microgrid Pikermi – Greece.
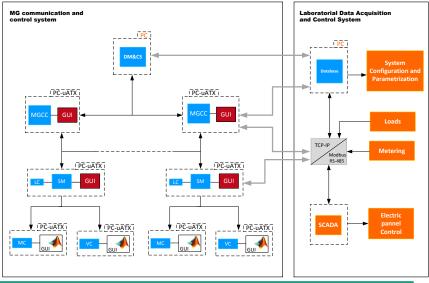
Small scale laboratory level examples: INESC Porto

- DC/AC microgeneration prototypes
  - Main functionalities:
    - Single-phase DC/AC inverters.
    - Solar inverter with MPPT power adjustment.
    - Active power control for voltage grid support.
    - Bi-directional communication with the MGCC.
    - Possibility of remote control.
  - Experimental Objectives:
    - Grid support by new voltage control strategies
    - Smart grid control and management architecture.

MicroGrid Central Controller (MGCC)
Microgeneration Controller (MC)
Vehicle Controller (VC)
Load Controller (LC)
Load
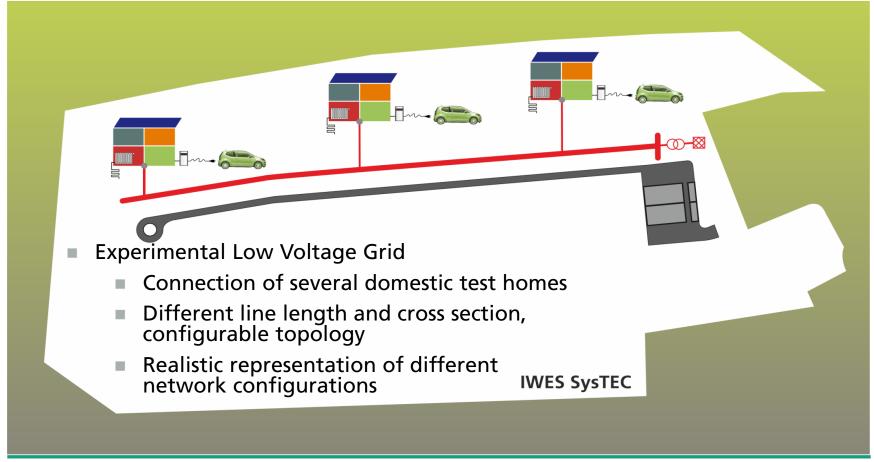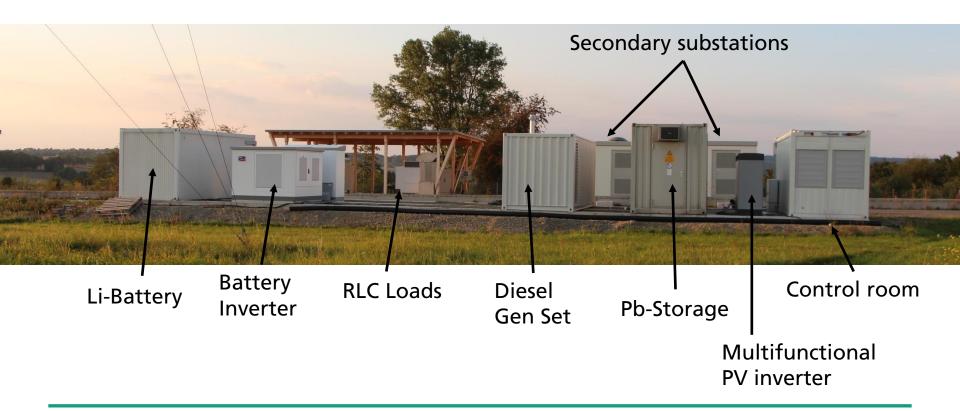
Large scale laboratory level: Fraunhofer IWES – SysTec Testing Field Hybrid Systems

■ **Testing operation in smart low voltage grids**

■ Experimental Low Voltage Grid

　■ Connection of several domestic test homes

　■ Different line length and cross section, configurable topology

　■ Realistic representation of different network configurations

IWES SysTEC

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Large scale laboratory level: Fraunhofer IWES – SysTec Testing Field for Hybrid Systems

■ Medium voltage test grid and hybrid system test bench

Secondary substations

Li-Battery

Battery Inverter

RLC Loads

Diesel Gen Set

Pb-Storage

Control room

Multifunctional PV inverter

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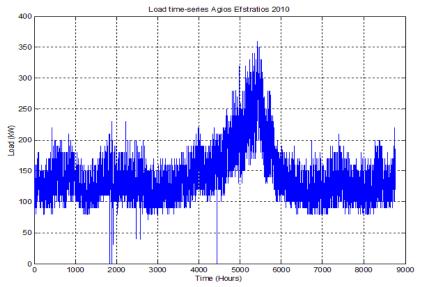
Demo site level: CRES

- **Agios Efstratios – Green Island National project**

  - Planning 100% RES penetration

  - Permanent population: 210

  - The population more than doubles for 1-2 months during summer

    - Wind: 600-800 kW

    - PV sys.: 150-250 kWp

    - Energy Storage: 3000-5000 kWh

    - Water electrolyser for H2 100 kW

    - Compressed Hydrogen Storage Tank of 200 kg of H2

    - Hydrogen-driven Genset 100 kW

    - Central Control and Data Acquisition System

Load time-series Agios Efstratios 2010

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Detailed description of microgrid projects and test facilities of DERlab members

- CIEMAT, Spain

- University of Seville, Spain

- National Technical University of Athens, Greece

- Technical University Sofia, Bulgaria

- Lodz University of Technology, Poland

- FOSS Research Center for Sustainable Energy, Cyprus

- CRES, Greece

- INESC TEC, Portugal

- Fraunhofer IWES, Germany

See Annex.

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Contact

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DERlab

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Phone: +49 561 7294 483

References

CIGRE 2015	CIGRE Working Group C6.22, „Microgrids 1 Engineering, Economics, & Experience", Technical Brochure 635, cigré, Paris, Frankreich, Oktober 2015
Höser 2015	Höser, Th., „Städtische Stromversorgung während eines langanhaltenden Stromausfalls", Bevölkerungsschutz 04/2015, Bundesamt für Bevölkerungsschutz und Katastrophenhilfe, Bonn, Deutschland, 2015
VDE-ETG 2015	ETG Task Force Grundsätzliche Auslegung neuer Netze, „Der Zellulare Ansatz", Studie der Energietechnischen Gesellschaftt im VDE (ETG), Frankfurt, Deutschland, Juni 2015
Electra	http://www.electrairp.eu/index.php
NETZ:KRAFT	http://forschung-stromnetze.info/en/projects/grid-restoration-with-future-power-plant-structures/
DERlab	http://der-lab.net/

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- INESC TEC, Portugal

- Fraunhofer IWES, Germany

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Large scale laboratory level: CIEMAT
Expertise in the Microgrid Research Topic

Ciemat

Centro de Investigaciones
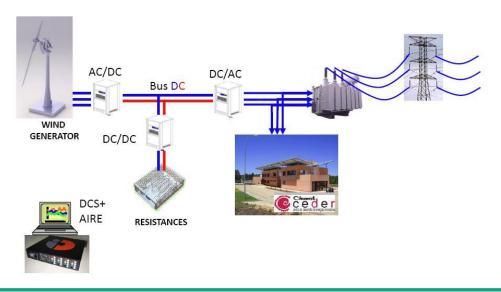Energéticas, Medioambientales
y Tecnológicas

- **Activities related to DER**
  - Research
  - Testing
  - Pre-standardization
  - (Small) wind
  - PV
  - Fuel Cells
  - Kinetic energy systems
  - **Microgrids**

- **Activities on Microgrid research**
  - SINTER Project
  - GEBE Project
  - HIBEOSOLEO Project

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Large scale laboratory level: CIEMAT
Experimental Facility for Testing

Ciemat
Centro de Investigaciones
Energéticas, Medioambientales
y Tecnológicas

■ Electrical

- Several buildings, operating as loads
- Transformers
- Renewable generators (solar 15kW, wind 100kW, 30 kW mini-hydro)
- Diesel generator set (50 kVA) with a clutch
- Storage systems (100+50 kWh Lead-acid, 50 kWh Li-ion, flywheel, hydrogen, supercapacitors)
- Dump load (40 kW controllable loads)

■ Communication

- distributed cable and OF network
- Monitoring & smart-meter network

■ Cold / Heat

- central district-heating and
- controllable 100kW electric boiler

■ Hydrogen

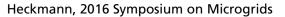- biomass gasifier and
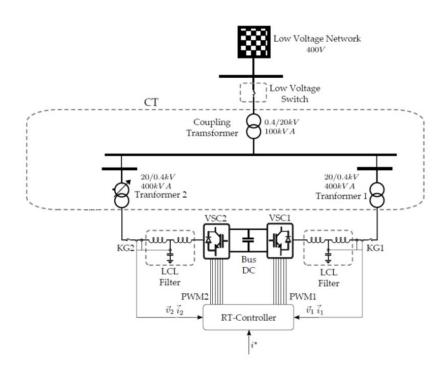- some H2 loads

Large scale laboratory level: CIEMAT

Large scale laboratory level: University of Seville
MV/LV research lab

■ One-line Diagram

■ MVL Transformers
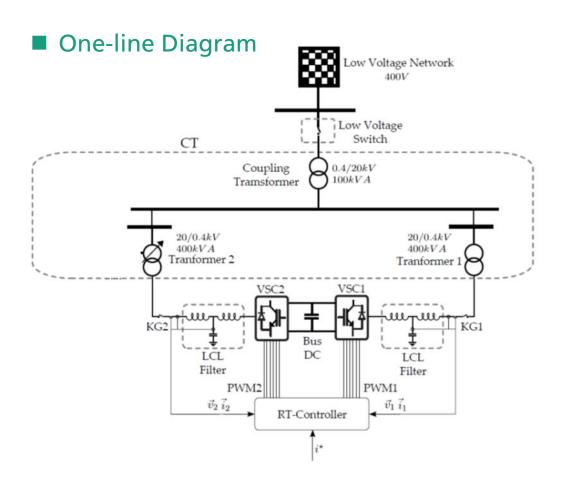
■ 0.5 MVA B2B VSCs

Large scale laboratory level: University of Seville
MV/LV research lab

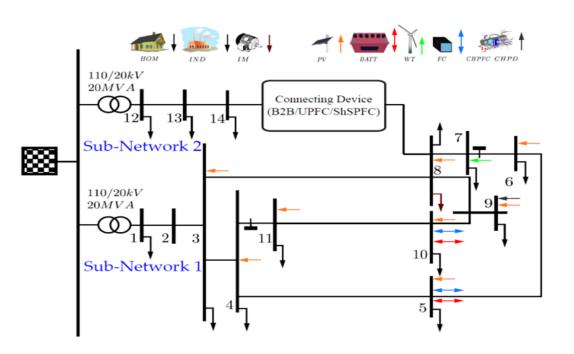- **One-line Diagram**

- **Testing capabilities**

  - LV devices:
    - Hardware:
      - D-STATCOM
      - VSC for PV plants
      - BESS
    - Software:
      - Advanced control algorithms for PE devices
  - MV devices:
    - Distribution OLTC

Large scale laboratory level: University of Seville
Active distribution networks research lab
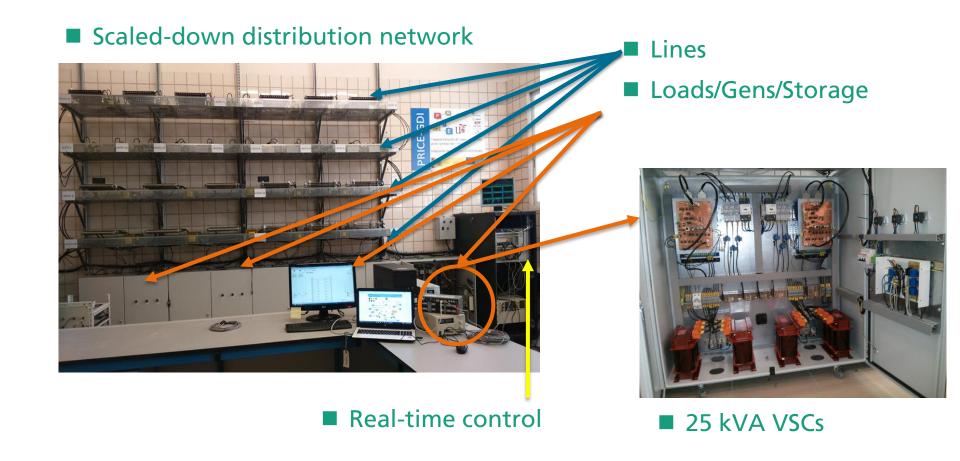
■ CIGRE task force C06.04.02

Actual German distribution network to analyse the impact of DG including:

■ DG (PV, wind, CHP)

■ Energy storage systems

■ Industrial/residential loads

■ Flexible links between radial feeders

Large scale laboratory level: University of Seville
Active distribution networks research lab

- **Scaled-down distribution network**

- **Lines**
- **Loads/Gens/Storage**

- **Real-time control**

- **25 kVA VSCs**

Large scale laboratory level: University of Seville
Active distribution networks research lab
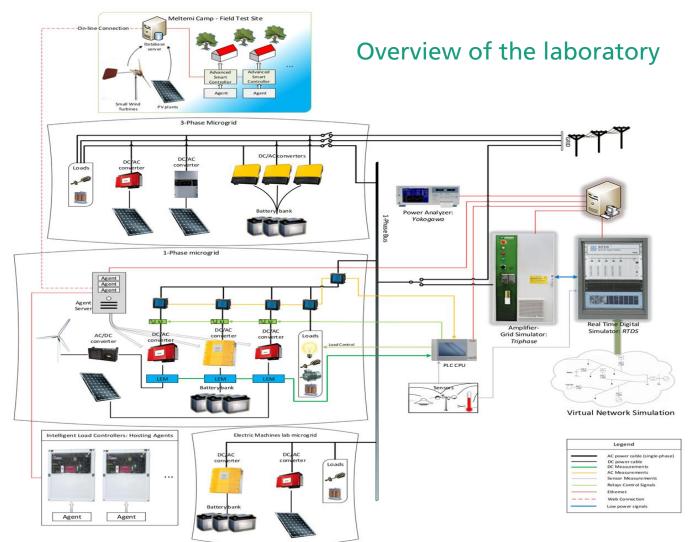
■ **Scaled-down distribution network**

■ **Testing capabilities**

- DG Integration in MV systems:
  - Modification of power flows
  - Voltage profiles
  - Losses
  - Impact of storage systems
- New tools for DMS:
  - Distribution state estimation
  - Volt/Var control
  - Centralized control of DG
- Advanced control algorithms for:
  - Renewable power plants
  - Storage systems

Large scale laboratory level: Microgrids at NTUA

Overview of the laboratory

Large scale laboratory level: Microgrids at NTUA
LV Microgrid and Hardware-in-the-Loop environment

LV Microgrid

RTDS   Power Amplifier

Large scale laboratory level: Microgrids at NTUA
LV Microgrid and Hardware-in-the-Loop environment
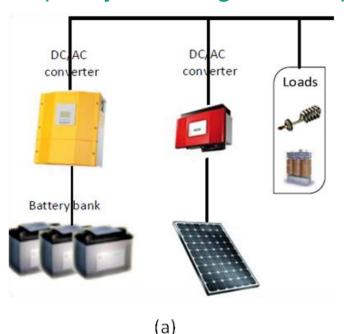
Battery inverter droop (P-f)

Voltage control

SCADA: measurements
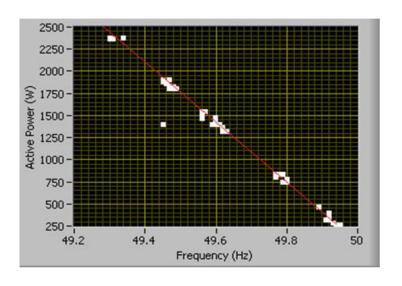
Large scale laboratory level: Microgrids at NTUA
Centralized Secondary control of Microgrid for frequency regulation

- Islanded microgrid consisting of PV generation, storage and controllable loads
- The battery inverter operates in droop mode, varying the microgrid frequency according to its output power
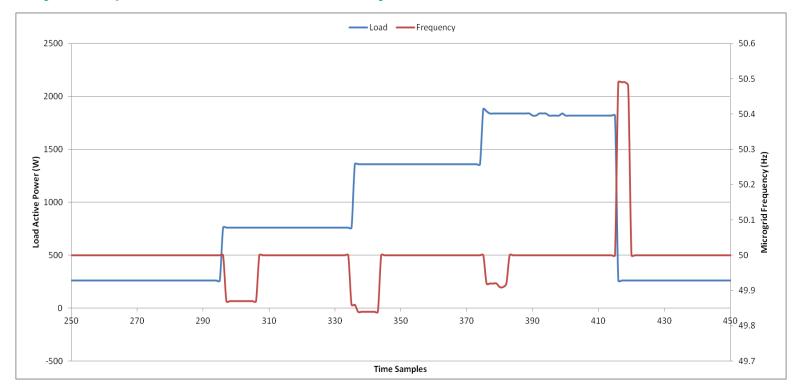
a) Laboratory setup for frequency restoration, b) Measurement of the frequency droop curve.

Large scale laboratory level: Microgrids at NTUA
Centralized Secondary control of Microgrid for frequency regulation

■ To restore the frequency back to the nominal value (50Hz), the frequency deviation is measured at each time-step and the droop curve is changed by a setpoint sent to the battery inverter

Active power and frequency of the microgrid with secondary frequency control

Large scale laboratory level: Microgrids at NTUA
Decentralized Secondary control in an Interconnected Microgrid

- DG units and load controllers are equipped with a certain level of autonomy in making decisions about the energy management of the microgrid.
- Applications:
  - Market participation of the Loads or the DG/RES
  - Formulation of a VPP +......
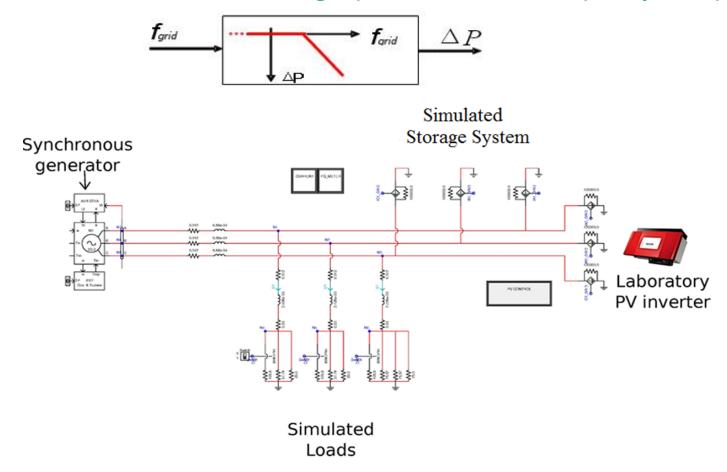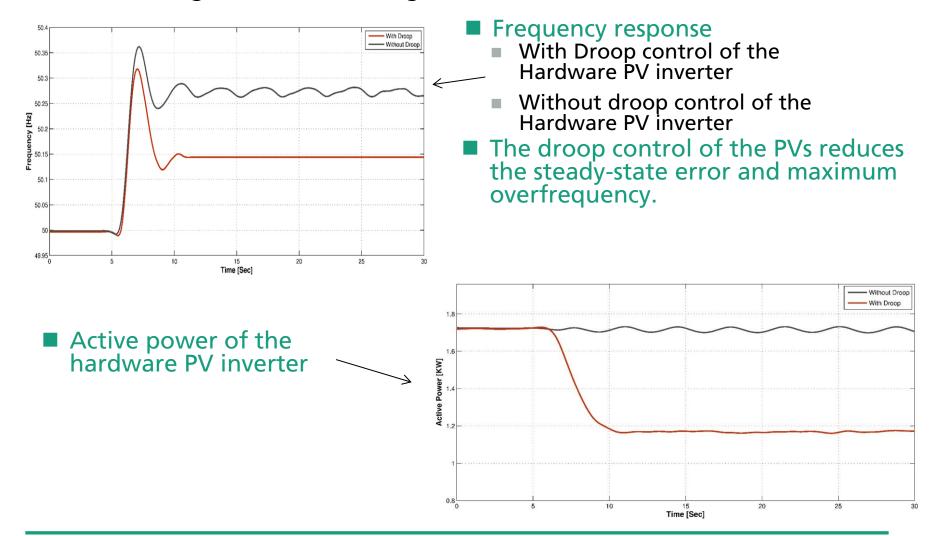
Large scale laboratory level: Microgrids at NTUA
Islanded microgrid at a PHIL configuration

■ Hardware PV inverter: 1kW single phase with over-frequency droop
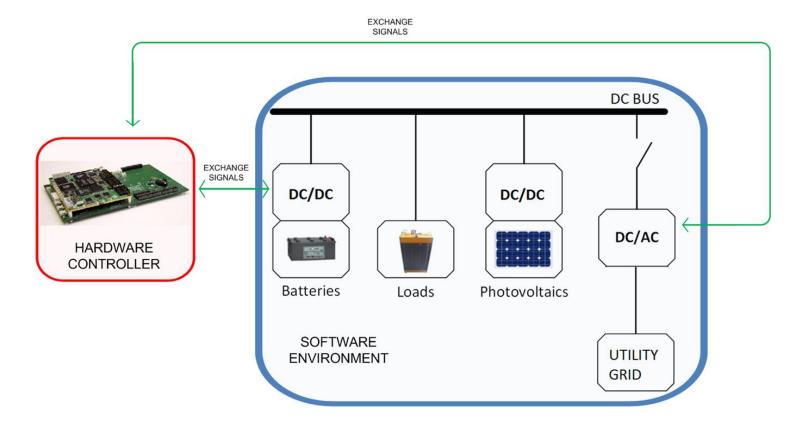
Large scale laboratory level: Microgrids at NTUA
Islanded microgrid at a PHIL configuration

- **Frequency response**
  - With Droop control of the Hardware PV inverter
  - Without droop control of the Hardware PV inverter
- **The droop control of the PVs reduces the steady-state error and maximum overfrequency.**

- **Active power of the hardware PV inverter**

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Large scale laboratory level: Microgrids at NTUA
Hardware-in-the-loop testing chain for DC Microgrid operation

■ **Control Hardware-in-the-loop infrastructure for testing Islanding detection methods on DC microgrids**
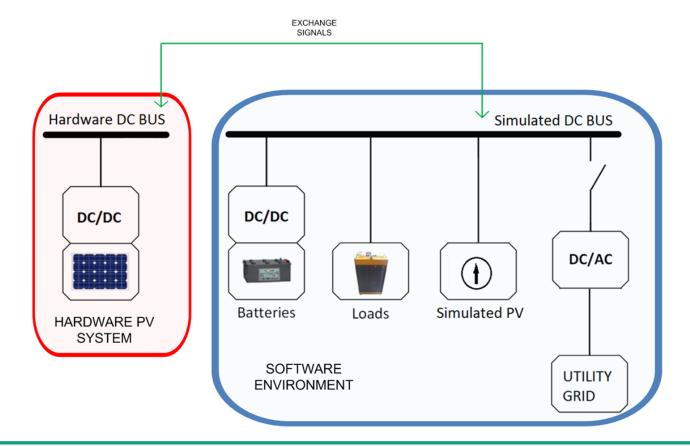
Large scale laboratory level: Microgrids at NTUA
Hardware-in-the-loop testing chain for DC Microgrid operation
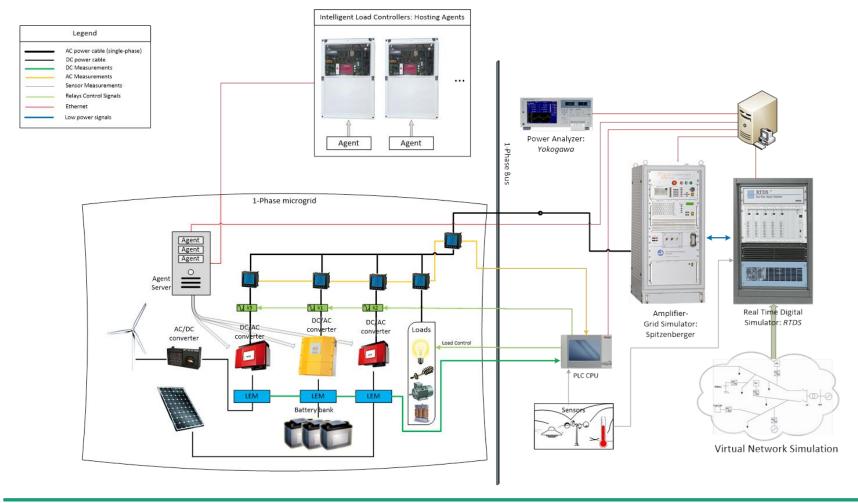
- Power Hardware-in-the-loop infrastructure for testing Islanding detection methods on DC microgrids

Large scale laboratory level: Microgrids at NTUA
Hardware-in-the-loop testbed for AC Microgrid centralized and distributed control strategies

Small scale laboratory level: TU Sofia R&DS Laboratory for DER systems

- **Power Electronics Laboratory**

  - Hybrid installation consists of a LV microgrid, Including, two SMA inverters, storage, controllable AC loads Chroma AC 63802, monitoring with Internet connection, Network connected and Island operation.

  - In April 2012 Installation was equipped with a SCADA and SIMENS PLC based Control System.

Small scale laboratory level: TU Sofia R&DS Laboratory for DER systems

- **Power Electronics Laboratory**

- Dr. Anastassia Krusteva
- Dr. Metody Georgiev
- Dr. Rad Stanev
- with co-support of Prof. D.Sc Michail Antchev

Small scale laboratory level: TU Sofia R&DS Laboratory for DER systems

- ## Power Electronics Laboratory

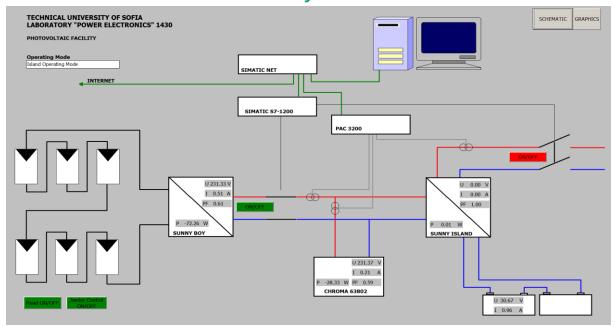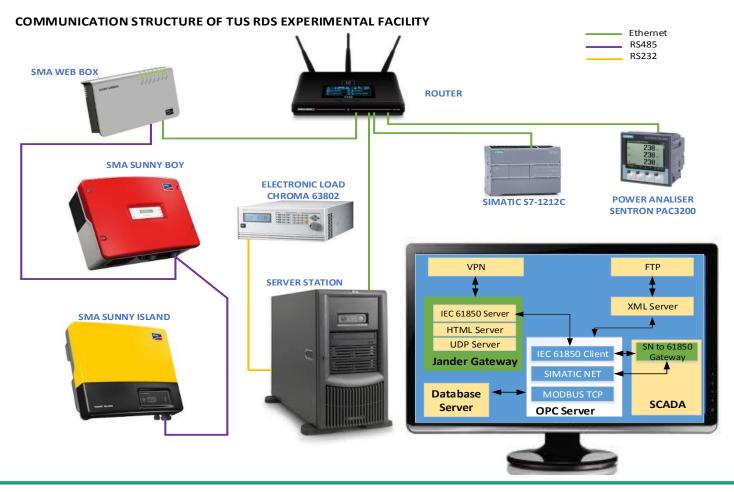**COMMUNICATION STRUCTURE OF TUS RDS EXPERIMENTAL FACILITY**

Small scale laboratory level: TU Sofia R&DS Laboratory for DER systems

Power Electronics Laboratory
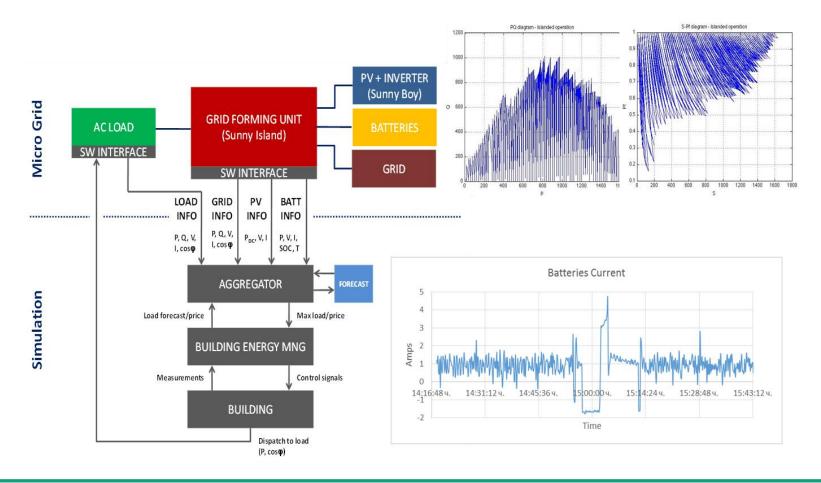
- Six PV units Sharp NT175
- PV inverter SMA Sunny Boy 1200
- SMA Sunny Island 2224 (grid-forming)
- Batteries CSB GPL121000 (12V, 100Ah)
- Controllable load Chroma AC 63802
- Windows-based computer with Internet connection
- SCADA control system and electrical connections remote monitoring and control of microgrid regimes were realized.

- Experimental regimes:
  - Normal Operation Mode (grid and PV are connected) – NOP
  - Grid Operation Mode (without PV generation) – GOM
  - Island Operation Mode landed, with PV generation) – IOM
  - Batteries Operation Mode (islanded, without PV generation) – BOM.

- JaNDER Gateway is installed in TUS-RDS PEL ensuring connection using IEC 61850 client and/or Web Browser.

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Small scale laboratory level: TU Sofia R&DS Microgrid remote control and testing

- ■ **"Smart Buildings and Renewable Energy Integration in Micro Grids"**

Small scale laboratory level: TU Lodz
Institute of Electrical Power Engineering

Lodz University of Technology
Institute of Electrical Power Engineering

The Laboratory of Distributed Generation (LDG) is loacated in Institute of Electrical Power Engineering at Lodz University of Technology. LDG serves for testing the integration of distributed generation with the power networks. This laboratory is designed to build, simulate and test microgrids and its interoperability with the power networks.

Sun tracking PV system 9 kWp

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Small scale laboratory level: TU Lodz
Institute of Electrical Power Engineering

- **Research Fields**

  - quality of supply in distribution networks with distributed resources,

  - application of energy storages for energy management and power quality improvement,

  - management and control systems for microgrids,

  - autonomous operation of microgrids,

  - integration of EVs with electrical power grid.
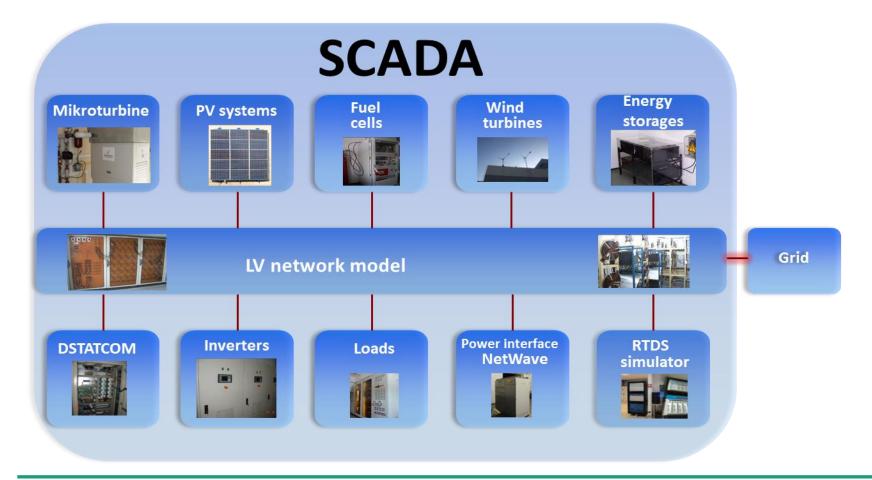
- **Technical Infrastructure**

  - renewable energy sources,

  - energy storage systems (including emulator of electric vehicle charging hardware),

  - energy sources utilizing traditional fuels,

  - supplementary devices supporting microgrid,

  - digital real time simulator - RTDS with power amplifier.

Small scale laboratory level: TU Lodz
Institute of Electrical Power Engineering

Lodz University of Technology
Institute of Electrical Power Engineering

- **General structure of laboratory**

DERlab

Fraunhofer
IWES

Small scale laboratory level: TU Lodz
Institute of Electrical Power Engineering

- **Research capabilities of Laboratory of Distributed Generation:**

  - implementation and testing of strategies and algorithms for microsystems management

  - utilization of energy storage systems with renewable energy sources,

  - DSM algorithms

  - use of power sources and ESS inverters to compensate the electromagnetic disturbances: voltage fluctuations, distortion and asymmetry currents

  - use of renewable sources and energy storage system to compensate the voltage dips

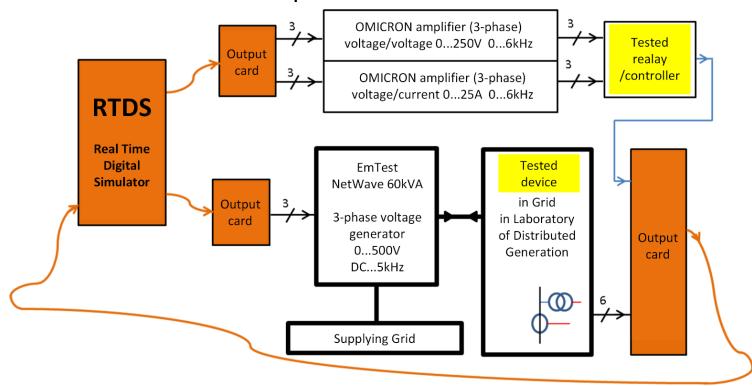 - microsystem management during the autonomous operation

- **Features of laboratory infrastructure**

  - State of the art equipment - the possibility and necessity to solve practical problems

  - Flexible structure and configuration - the ability to build customized microsystems

  - Versatile measuring and controlling systems

  - Remote access to the measurement and control systems - the ability to perform research in the periods determined by environmental conditions

  - Simultaneous operation of several electrical networks

Small scale laboratory level: TU Lodz
Tests capabilities using RTDS

- ■ **Versatile tests utilizing the Real Time Digital Simulator:**
  - ■ Hardware in the Loop
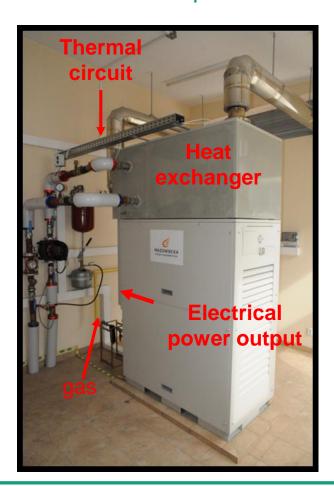 - ■ Software in the Loop

Different setups for Hardware in the loop tests
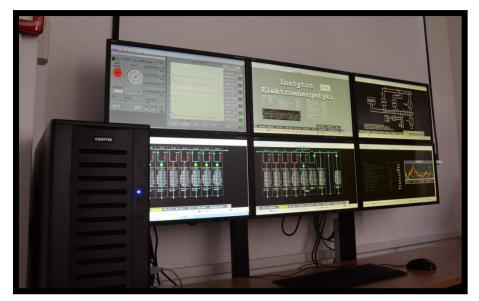
Small scale laboratory level: TU Lodz
Cogeneration system

■ **Microtubine Capstone C30**

Thermal circuit

Heat exchanger

Electrical power output

gas

- Electrical power putput: P_{el} = 30 kW

- Thermal circuit output: P_{ci} = 60 kW

■ **Microtubine control over SCADA**

Small scale laboratory level: TU Lodz
Versatile Energy Storage Systems with Customized Inverter

ABB
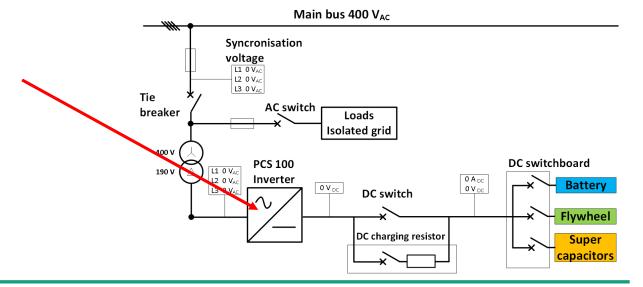
Parametr	Unit.	AGM batteries	Vycon Flywheel	Super-capacitors
Nominal power	kW	50	350	300
Energy	kWh	50	0,68	0,65
DC voltage	V	520	520-540	300-600
Discharge time (nominal power)	s	3600	7	7
Rotating speed	rpm		38000	
Capacity	F			12,5

■ **PCS100 ESS**

Small scale laboratory level: TU Lodz
Tests Examples utilizing Energy Storage System

- **Microturbie Capstone C30**

    - Integration with RES:
        - storing energy in periods of excess power production
    - Load leveling
    - Managing of peak loads
    - Load shifting

- **Ancillary Services**

    - Uninterruptable power supply during voltage sags and power interruption,
    - Compensation of electromagnetic disturbances (improving of electrical power quality)

Small scale laboratory level: Cyprus University
Research Center for Sustainable Energy (FOSS)

- Cyprus university campus is transforming into a truly living lab with state of the art technologies and sources capable of operating as a microgrid control area.
- A planned fully functioning microgrid infrastructure – A test bed for related technologies and systems for research, development, training and education
- Already erected or planned to be erected:
    - Local PV generation directly connected to the local grid (350 kWp already connected and operated as self-consumption – 10 MWp to be operational by December of 2017).
    - 1 MWhr electrochemical storage facilities (2017) that will increase load management capabilities, improve operational capabilities and offer services to the local DSO
    - 1 MW thermal equivalent system of 4 heat pumps for the planned extensions of the university
    - Smart meter facilities capable of offering valuable data and local control for the development of demand side management and demand response
    - Full broad band connectivity with the local DSO using fibre optic cables and PLC
    - A smart energy management system for demand scheduling and control
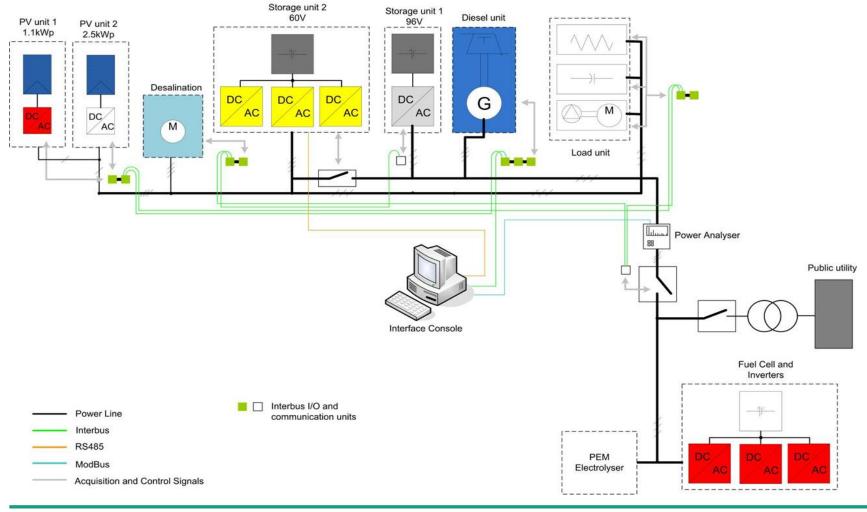- Coming:
    - Additional smart sensors and distributed controllers for completing the smart microgrid architecture including island networks within the university campus capable of facilitating targeted research work without affecting the rest of the campus. All to be completed by 2020 …

Demo site level: CRES Microgrid, Pikermi, Greece

System Diagram
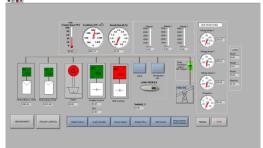
Demo site level: CRES Microgrid, Pikermi, Greece

- **Configuration**

  - 2 Photovoltaic arrays (1,1 and 4,4kWp)

  - 2 Battery storage systems (40 kWhs each)

  - 1 Diesel generator (12,5kVA)

  - 1 PEM Fuel cell (5kW)

  - Controllable load bank (13kW)

  - Interconnection to public grid

  - Data Acquisition and contol using interbus

  - Supervisory control console developed in LabVIEW

Demo site level level: CRES
DERri Transnational Activities projects

- ## Carbon Agents for Virtual Power Plants
  - Implementation and testing of a Multi-Agent System for the operation of a VPP in terms of CO_2 emissions. The project was done in cooperation with Cardiff University (UK) and ICCS/NTUA (GR).

  http://www.der-ri.net/uploads/media/FactSheet-CA_VPP_GF_20120717.pdf

- ## Stohastic Optimal Predictive Control for Microgrids
  - Implementation of a centralized Stohastic controller for the management of the microgrid in terms of energy market criteria. The project was done in cooperation with Sannio University (IT).

  http://www.der-ri.net/uploads/media/FactSheet-SOPC_GF_20120717.pdf

- ## Microgrid Stohastic Predictive Control
  - Extension of the previous project considering also aspects such as thermal need coverage and CO_2 emissions produced by the microgrid

  http://www.der-ri.net/uploads/media/FactSheet-MSPC_GF_20120717.pdf

Demo site level level: CRES

MIRABEL: Micro-Request-Based Aggregation, Forecasting and Scheduling of Energy Demand, Supply and Distribution (FP7)

- Development of approach that allows energy distribution companies to balance the available supply of RES and the current demand.
- Testing of the developed technology in CRES microgrid under two main scenarios:
    - Grid connected household community
    - Isolated Distribution Grid (Local Distributor of Energy-LDE)
- Test objectives
    - Assessment of developed product in terms of operation of its components (flex-offers, forecasting, aggregation, scheduling)
    - Evaluation of the overall performance in terms of energy balance, RES/conventional generation ratio, energy efficiency etc.

http://www.mirabel-project.eu/

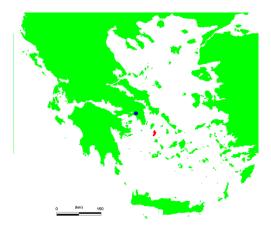# Demo site level level: CRES
Gaidouromantra "islanded" Microgrid in Kythnos island, Greece

- **PROJECTS 1999- 2013**
  - 1. PV-MODE, JOR3-CT98-0244
  - 2. MORE, JOR3CT98-0215
  - 3. MORE MICROGRIDS,
  FP6 No. 019864
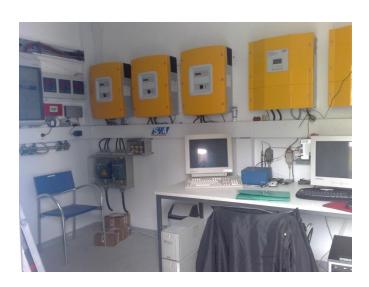
Demo site level level: CRES
Gaidouromantra "islanded" Microgrid in Kythnos island, Greece

- **Objectives of the project:**
  - Design, implement and operate an inverter based electric power system powered from Photovoltaics offering basic quality electricity service

  - Development of control and management techniques, for storage, PV generators and non-critical loads for reliable and effective operation

  - Before 2001, there was no grid and 4 houses out of 12 had a diesel generator.

  - The site was chosen because at the time it was far from the MV grid (5 km), now the closest MV pole is about 700 m away.
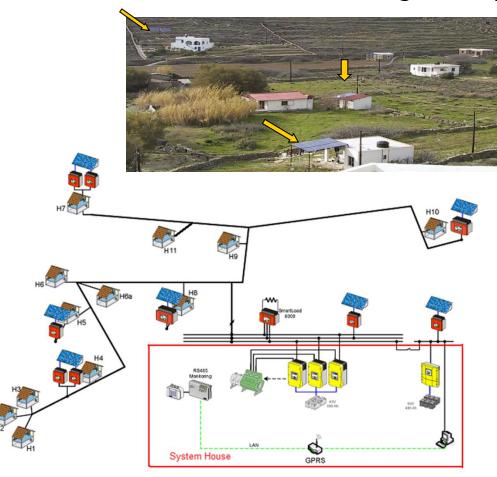
Demo site level level: CRES
Gaidouromantra "islanded" Microgrid in Kythnos island, Greece

- 12 Vacation Houses
- 6 Distributed PV sys capacity 12.5 kWp
- 50 kWh Battery bank,
- Lead acid OPzS
- 9kVA Diesel genset
- 3-phase LV grid formed by 3 Sunny Island 5048 Inverters
- System Operation April 2001 to Present
- Change of Inverters in 2008
- Battery bank changed in October 2009

Demo site level level: CRES
Gaidouromantra "islanded" Microgrid in Kythnos island, Greece

- **Further Work in Gaidouromantra, Kythnos island**

    - CRES is responsible for continuing monitoring, servicing and maintaining the microgrid

- **The following ideas are suggested for a future R&D project in Gaidouromantra microgrid, Kythnos Island:**

    - Interconnection of the Gaidouromantra microgrid with the Kythnos island Medium voltage grid and optimization of the microgrid operation in islanded and inter-connected mode to make use of the excess PV energy.

    - Development of the required protection measures, communication and control of an active (bi-directional) Low Voltage - Medium Voltage transformer as well as ancillary services and business models.

Demo site level level: CRES
Agios Efstrations – Green Island National project

- **Planning 100% RES penetration**
- **Permanent population: 210**
- **The population more than doubles for 1-2 months during summer**
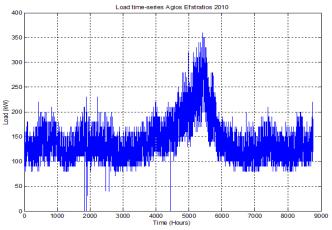
  - Wind: 600-800 kW
  - PV sys.: 150-250 kWp
  - Energy Storage: 3000-5000 kWh
  - Water electrolyser for H2 100 kW
  - Compressed Hydrogen Storage Tank of 200 kg of H2
  - Hydrogen-driven Genset 75-100 kW
  - Central Control and Data Acquisition System

Demo site level level: CRES
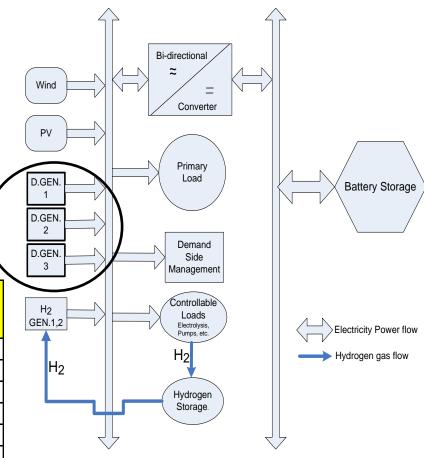## Agios Efstrations – Green Island National project

- The system operation simulation and comparison with historic electricity production cost data show that the implementation of a RES based power system for the island is cost effective, with a LCOE of less than half of the conventional diesel fuel powered system.

Year or Scenario	Variabale cost of electricity in €/MWh	Fixed cost of electricity in €/MWh	Total cost of electricity in €/MWh
2002	--	--	373.46
2008	312	331.65	643.65
2010	225	331*	556
Scenario 1 (3.345 MWh/day)	--	--	200
Scenario 3 (3.345 MWh/day)	--	--	234
Scenario 5 (5.352 MWh/day)	--	--	199
Scenario 7 (5.352 MWh/day)	--	--	200

*: Assuming that the fixed cost did not change between 2008 and 2010

Existing Power System

Basic block diagram of Agios Efstratios RES Electrification system including Hydrogen components.

Heckmann, 2016 Symposium on Microgrids
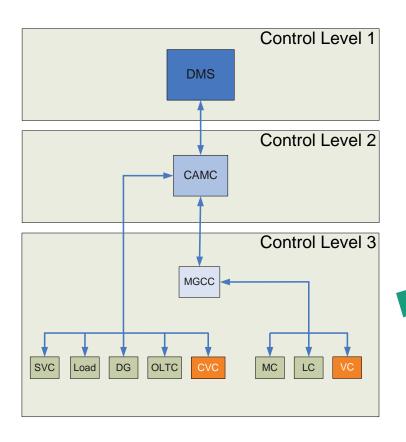
45

Demo site level level: CRES
Conclusions

- Coincidence of seasonal peak of PV and Wind energy production in islands during the tourist high demand season in the summer

- Photovoltaic systems are complementing Wind turbines' energy production in Greek autonomous island Electric Systems up to annual RES energy penetration of about 15% without any control requirements

- In the annual RES energy penetration range from 15 to 25%, monitoring and sending operation set-points for control of wind parks' power output and next day forecasting of Wind and distributed PV plants (under 100 kWp) permits scheduling planning of thermal power plants for stable operation and voltage support in the LV grid, allowing sometimes RES instantaneous power penetration to exceed 60%.

- Further PV and variable renewable energy systems penetration in islands requires either connection to a larger electrical system such as the mainland system in Greece that works as a buffer for electricity flows and/or

- Integration of storage, demand response, generator production control and of course in parallel introduction of intelligence and communication applications in monitoring and controlling the grid, distributed resources and loads (i.e. Smart Grids)
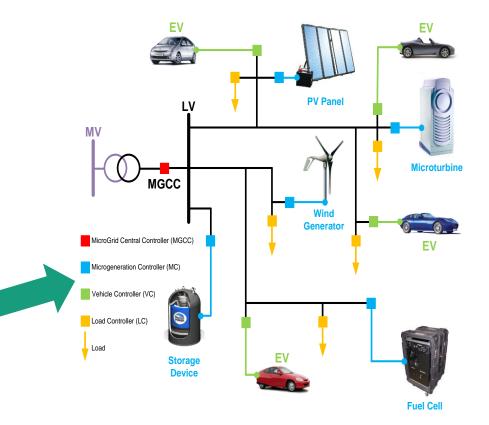
Small scale laboratory level: INESC TEC
MG as smart distribution cell

- **The MG is a flexible, active and controllable LV system, incorporating: Microgeneration, Storage devices, Electric vehicles**
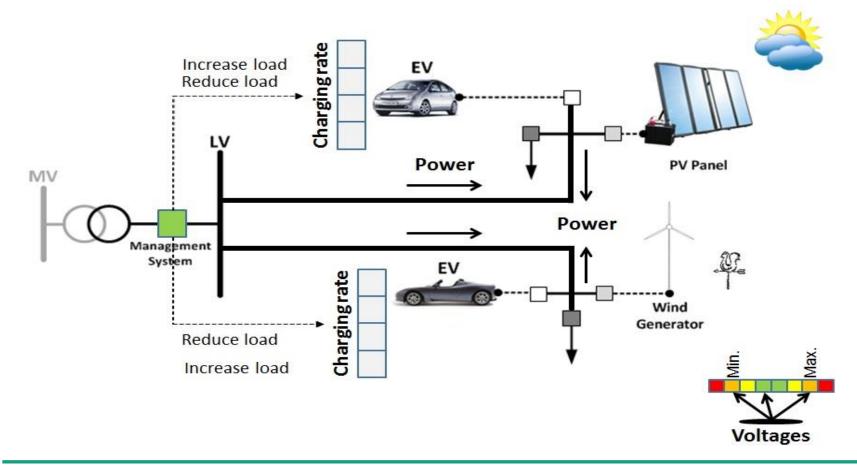
Small scale laboratory level: INESC TEC
MG as smart distribution cell

- **Technical challenges – Integrated management of EV and RES**

Small scale laboratory level: INESC TEC
MG as smart distribution cell

- **The MG can be regarded as the cell of future Smart Grids:**

  - Enhance the <u>observability</u> and <u>controllability</u> of power distribution systems.

  - <u>Actively integrate electric vehicles</u> and loads in the operation of the system.

  - <u>Increase the connection capacities for different distributed generation technologies.</u>

  - Promote the coordinated management of microgeneration, storage, electric vehicles and load, in order reduce system losses and improve power quality.

  - <u>Provide self-healing capabilities</u> to the distribution network, due to its ability of operating autonomously from the main grid and perform local service restoration strategies.

Small scale laboratory level: INESC TEC
Validation of MG operation concepts

Merge - Mobile Energy Resources in Grids of Electricity

■ **Main goals and achievements:**

- Development of a **management and control concept** that will facilitate the actual transition from conventional to EV.

- **Identify potential smart control approaches** to allow the deployment of EV without major changes in the existing network and power system infrastructures.

- To identify the most appropriate ways **to include EV into electricity markets** through the smart metering infrastructure.

- To provide **quantitative results on the impact of integrating EV into the grid** of EU national power systems.

- To provide **computational suite** able to identify and quantify the benefits that a progressive deployment of the MERGE concept will bring to the EU national power systems, taking into account several possible smart control approaches.

Small scale laboratory level: INESC TEC
Validation of MG operation concepts

REIVE

- **Main goals and achievements:**

    - Study, **develop and test of technical solutions and pre-industrial prototypes** for the active and **intelligent management of electricity grids** with large scale integration of **microgeneration and electric vehicles**.

    - Develop a technical platform which:
        - is able to identify and quantify the benefits of a progressive deployment of EV and microgeneration technologies.
        - includes innovative control solutions for microgeneration and EV systems.

    - **Development of a laboratorial infrastructure – The MG and EV laboratory.**

    - Support industrial partners in order to deploy the technologies and products resulting from the concepts and prototypes developed.

    - To propose a regulatory framework capable of:
        - integrating EV users in a fair and non-discriminatory way,
        - deal with the additional investments in the network control and management structures in order to reliably accommodate a large number of EV.

Small scale laboratory level: INESC TEC Smart Grids and Electric Vehicles Laboratory

- **Main objectives:**

  - Development and testing of prototypes

  - Development and testing of control devices and integrated management solutions

  - Development of tests of communication solutions for smart metering infrastructures

  - Testing EV batteries control and management

  - Testing microgeneration control and management solutions

  - Testing Active Demand Response and home area networks

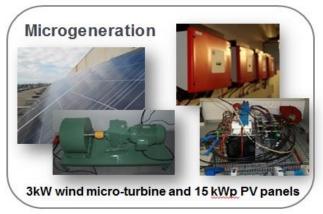 - Developing and testing stationary storage and its control solutions for Smart Grids

Small scale laboratory level: INESC TEC
Smart Grids and Electric Vehicles Laboratory

- Infrastructure

Small scale laboratory level: INESC TEC Smart Grids and Electric Vehicles Laboratory

■ **Electric infrastructure:**

- Renewable based microgeneration
- Storage
- Resistive load bank – 54 kW
- LV cables emulators (50 A and 100 A)
- Plug-in electric vehicles – Renault Fluenze ZE and twizy
- Microgeneration and EV power electronic interfaces
- Electric panel, command and measuring equipment

15 kWp photovoltaic panels

25 kWh capacity Flooded Lead-Acid (FLA)

128 Lithium battery cells

3 kW wind micro-turbine

Small scale laboratory level: INESC TEC Smart Grids and Electric Vehicles Laboratory

■ **Infrastructure: commercial DC/AC microgeneration inverters**

The two 25 kW FLA battery bank are connected to two three-phase groups of grid forming inverters – SMA Sunny Island inverters, enabling:

- Testing MG islanding operation.

- The inverters provide the voltage and frequency reference to the isolated system, based on P-f and Q-V droops.

The PV and wind turbine emulator can be coupled to the network through:

- Three DC/AC SMA Sunny Boy Inverters with 1.7 kW nominal power.

- DC /AC SMA Windy Boy Inverter with 1.7 kW nominal power.

The main objective is to explore the microgeneration commercial solutions and study potential limitations
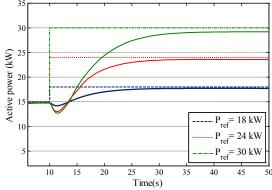
Small scale laboratory level: INESC TEC Smart Grids and Electric Vehicles Laboratory

- **Controllable microgeneration emulator - 4 quadrant AC/DC/AC inverter**

  - The laboratory is equipped with a 20 kW three-phase AC/DC/AC custom-made four-quadrant inverter.

  - The inverter power is controlled in order to emulate the response of controllable power sources such as Single-Shaft Microturbines or Fuel Cells.

  - Enable the development and test of new frequency and voltage control strategies, in order to provide grid support during emergency conditions:

    - Microgrid islanded operation.

    - Microgrid restoration procedure.

IWES-SysTec
Test Centre Smart Grids and E-Mobility

Outline:

1. Overview SysTec
Test Centre Smart Grids and E-Mobility
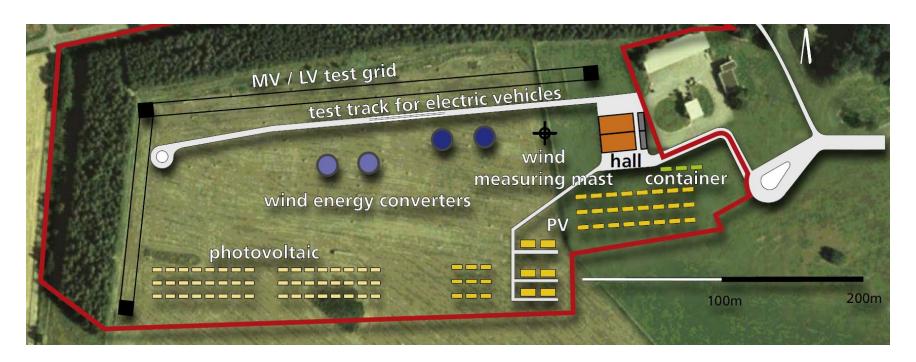

600m² lab area
80 000 m² open area
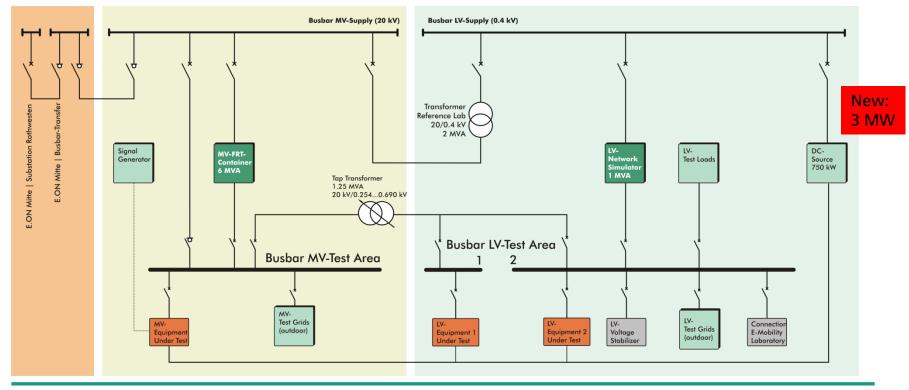
1. Overview SysTec
Outdoor Facilities

- Photovoltaic Systems, Wind turbine Generators(planned), Hybrid Systems
- Electrical Test-Networks (LV,MV)

- Charge Infrastructure for E-Mobility
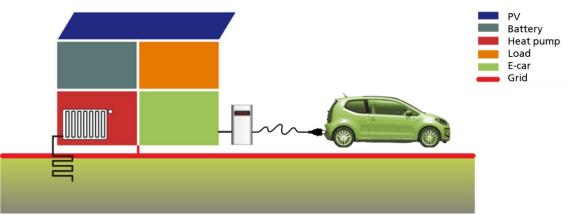- Test track for inductive charging systems

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2. SysTec - Testing Laboratory for Grid Integration (PNI)
Electrical Setup

- Development- and Test Facility for quasi-stationary and dynamic testing of the grid interface of DER units and Systems (low- and medium voltage)

Heckmann, 2016 Symposium on Microgrids

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4. SysTec - Testing Fields for Photovoltaic and Hybrid Systems
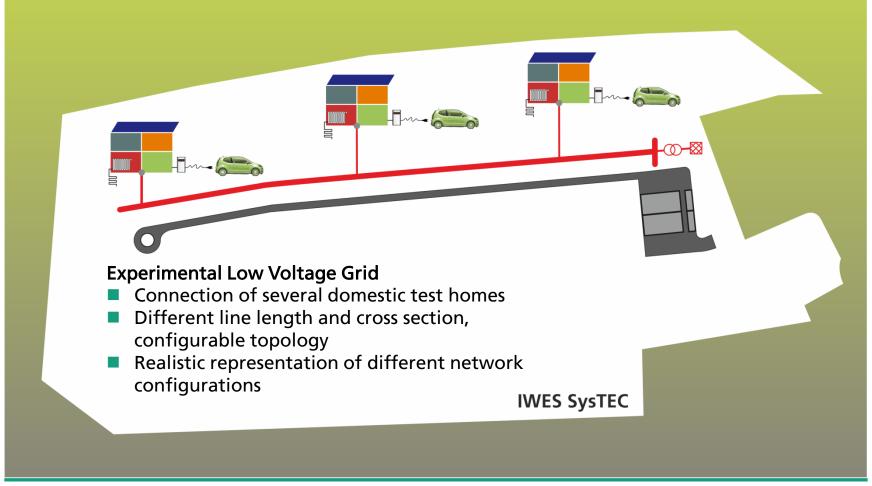## Testing integration into domestic homes / smart homes

- Representation of households / test houses
- 3 small buildings
  - roof integrated PV
  - electrical storage
  - heat pump
  - different household loads
  - charging stations for electric vehicles
  - energy management system
- 1 flexible test container "bring your own house"
- Measurement equipment
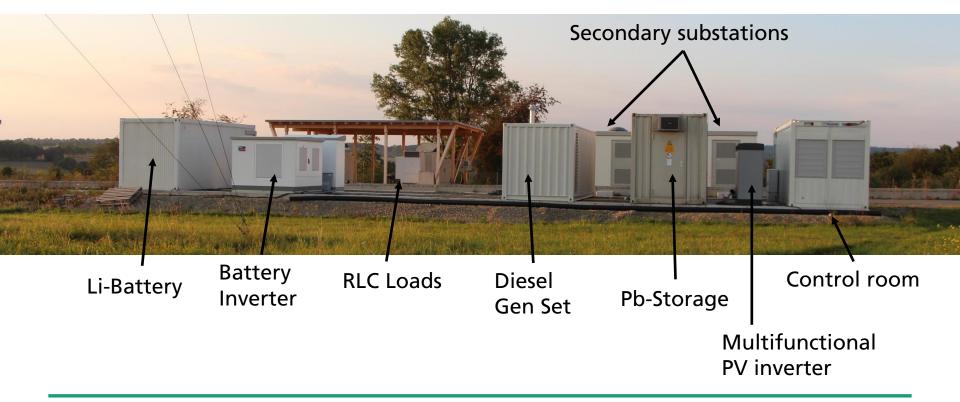
PV
Battery
Heat pump
Load
E-car
Grid

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Testing operation in smart low voltage grids

Experimental Low Voltage Grid
- Connection of several domestic test homes
- Different line length and cross section, configurable topology
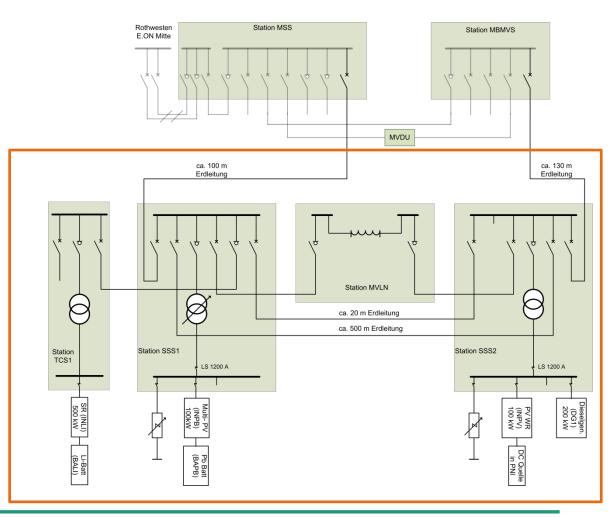- Realistic representation of different network configurations

IWES SysTEC

4. SysTec - Testing Fields for Photovoltaic and Hybrid Systems
Medium voltage test grid and hybrid system test bench

Secondary substations

Li-Battery

Battery Inverter

RLC Loads

Diesel Gen Set

Pb-Storage

Control room

Multifunctional PV inverter

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4. SysTec - Testing Fields for Photovoltaic and Hybrid Systems
Medium voltage test grid (20kV)

Features

- Operation modes: Islanded or interconnected

- Two main substations interconnectable with different line lengths

- Physical network emulation for the representation of different line length (up to 30 km)

- Controllable loads

- Generation units: Diesel gen-set, PV inverter

- Electrical Storages: Pb and Li storage systems

- Space for additional customer systems

Heckmann, 2016 Symposium on Microgrids

5. SysTec - Applications
Active and smart secondary sub-stations

- **Application and tests of system concepts with different components**

    - **Controllable MV/LV transformers**

    - **Controllable PV-inverters**

    - **Local voltage stabilizer**

    - **Controllable loads and storages**

- **Well tuned system for dynamic voltage control**

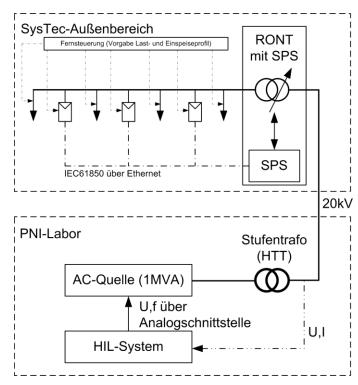- **Proof of concept and implementation by lab tests and pilot tests**

Prototype of a controllable MV/LV transformer made by J. Schneider Elektrotechnik GmbH. Tests in SysTec for the Project „Aktives, intelligentes Niederspannungsnetz"

DERlab

Fraunhofer IWES

5. SysTec - Applications
Active, intelligent LV networks

- **Critical network conditions can be tested selective and reproducible**
  - **Configurable LV networks**
    - **Topology**
    - **Cable cross-section**
  - **Controllable Loads**
  - **Adjustable PV**
- **Validation of components and methods before operation in a real network with real customers**
- **Optimization of control algorithms**
- **Usage of HiL methods**

Experimental setup of the project „Aktives, intelligentes Niederspannungsnetz".

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