Microgrid Research Programme and Laboratories

Microgrid Research Activities

Microgrid Projects
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.
- Approximately 250 students
- Approximately 100 PhD students
- Approximately 40 faculty members
- Approximately 20 TAPs (technical administrative employees)
- Approximately 50% of the turnover comes from external projects
Keywords: Energy Production – Energy Distribution – Energy Consumption – Energy Control

MicroGrid Research programme: www.microgrids.et.aau.dk
The MGTeam has published more than 80 articles (mainly IEEE journals and conferences) in 2014 and about 65 articles during the first half of 2015.
General aspects of a MicroGrid: “Definition and Operation”

The concept of Microgrids

Grid connected mode

Islanded mode

Main Utility Grid

PCC

EMS

IBS

Renewable Energy Resources

Electric Vehicles

PV

WT

Power Electronics

Household appliances and electronics

Compressed Air System

Smartmeters

Flywheel

EV

MicroGrid Research programme: www.microgrids.et.aau.dk
Hierarchical Control for MicroGrids

Microgrids Concerns...

- Power Quality enhancement
- Islanding capability and independence
- Energy cost saving and high efficiency
- System recovery under faults (selfheal)

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

MicroGrid Research programme: [www.microgrids.et.aau.dk](http://www.microgrids.et.aau.dk)
How to Coordinate harmonic/unbalance compensation?

The Whac-a-mole effect

Primary control
Harmonic virtual impedance

Secondary control
Harmonic/unbalance coordination control
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).
Issues in MicroGrids: \textit{Protection}s

\begin{itemize}
  \item \textbf{Ultra Fast communication link}
    \textit{(second line of defense)}
\end{itemize}

\begin{itemize}
  \item \textbf{Source Protection}
  \item \textbf{Network Protection}
  \item \textbf{Bidirectional Protection}
\end{itemize}

MicroGrid Research programme: \url{www.microgrids.et.aau.dk}
Traditional consumer

- Passive
- Only loads – fixed by the consumer
- No storage
- Electricity/thermal energy not coupled
- Manual management
- Load-dependent power quality
- Unidirectional power flow
- Considers only local residential energy

Future prosumer

- Active
- Shiftable loads/generation
- Storage systems/EV
- EMS take care of global energy objectives
- Power quality system control
- Bidirectional power flow according to energy hourly pricing, etc.
- Considers both local-residential and global-neighborhood energy requirements
Microgrid Research Programme

5 Years Road Map

- Microgrids and minigrids in emergent countries and rural areas
- AC and DC grids for ships and aircrafts
- AC/DC microgrids protections

- DC microgrids and DC homes
- AMI for AC/DC microgrids
- MV microgrids and Hybrid ESS
Microgrid Research Laboratory
Every setup is able to emulate a multi-converter low-voltage Microgrid, local and energy management control programmed in dSPACE real-time control platforms.
The laboratory is based on 6 Setups:

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

**Microgrid Research programme:** [www.microgrids.et.aau.dk](http://www.microgrids.et.aau.dk)
Microgrid Research Laboratory

- dSPACE based setup
- Ethernet 1 for dSPACE compiling
- Ethernet 2 for local communication
- USB wireless port for communicating with central EMS

Wireless Communication Links

PC Local EMS

Linksys wireless router

Ethernet cable

PC Central EMS

Microgrid Research programme: www.microgrids.et.aau.dk
Real-time control and monitoring platform through Control-Desk

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

Microgrid Research programme: www.microgrids.et.aau.dk
Microgrid Central Controller – EMS in Labview

Islanded MG
Unbalance Comp.

PCC Voltage 7
Unbalanced Load 1 7
Load 2 7

DC link Voltage 7

System Status
Protection

Vdc 656.43 V

Inverter 1
Inverter 2
Inverter 3
Inverter 4

dSPACE

Voltage Unbalance Information

VpcNd chart
VpcNd 1.01 V

VpcNq chart
VpcNq 0.52 V

VUF chart
VUFpcc 0.25 %

VUF on PCC 0.25 %

Unbalance Compensation Secondary Control

Comp. Activation
reset comp. ctrl

UFref 0.25
proportional gain (Kc): 0.300

LoopStep
integrator time (Ti, min): 0.001
derivative time (Td, min): 0.000

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

Load Main Grid . . . to Workstation 3-6

Power flow

Local distribution network

Main Grid

PV

Load

Workstation 1

PV

Workstation 2

PV

WT

Load

Microgrid Research programme: www.microgrids.et.aau.dk
Keep updated with our Microgrid research activities and projects

AAU Microgrid group in

Linkedin

Microgrid Research programme: www.microgrids.et.aau.dk
Microgrid Research Programme and Laboratories

Microgrid Research Activities

Microgrid Projects
Distributed Active Synchronization for Microgrid Under Unbalance and Harmonic Distortions

MicroGrid Research programme: www.microgrids.et.aau.dk
DC Microgrids Operation and Control

- Remote **telecom** applications
- **Coupled** renewable systems
- DC **powered homes**
- Fast **HEV** charging stations
**Tens of Demonstration Microgrids Constructed**

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

**PV Microgrid@Yushu**

2 MW

PV Microgrid@Yushu

MicroGrid Research programme: [www.microgrids.et.aau.dk](http://www.microgrids.et.aau.dk)
Microgrids in China – 30 MicroGrids

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

= 30 Microgrid demonstration Total Power: 1.2 GW

MicroGrid Research programme: www.microgrids.et.aau.dk
Microgrids in China – Business Model

DSO

1.42 rmb/kWh

PCC

1.00 rmb/kWh

Auto-consumption

MicroGrid Research programme: www.microgrids.et.aau.dk
Micro-Grid Technology Research and Demonstration

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

MicroGrid Research programme: www.microgrids.et.aau.dk
200kW Microgrid based on wind/PV/storage hybrid system
**PV power generation subsystem**

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

Satellite vertical view of Plant B

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

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

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

50kVA Bi-Directional Converter + Lead-Acid battery

Operation modes:
1. Constant current
2. Constant power mode

ESS is lead-acid battery, using
500 2V160AH lead-acid batteries 500V/320AH

battery group: 2 parallel of 250 series
Discharge depth is 65%
@50 kW inverter work about 2 hours @full capacity
Smart grid in Denmark – Omnia Project

Kamstrup Omnia scheme in iMGlab

SmartMeters

OMNIPOWER

OMNICON

In-House Display

Smart Energy Zigbee

EN 13757-5 Radio Mesh

COSEM GPRS/3G/Ethernet

OMNICATION

2G/3G

MGCC

EMS

AC power line
DC power line
DSF Sino-Danish project 2014-2017

Intelligent DC Microgrid Living Lab

i-DClab

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

- **Industrial DC Microgrid Living Lab**, At North China Electrical Power University (China), for research, demo and test of energy solutions for commercial buildings.

http://www.idclab.et.aau.dk
Intelligent DC Microgrid Living Lab

Demonstration of DC-home with Real DC appliances.

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

http://www.idclab.et.aau.dk
Intelligent DC Microgrid Living Lab

DC Home Laboratory Power Architecture

Whisper WT
PV Panels
Grid
Microgrid Laboratories
μCHP
Heat Storage
Radiators

230 VAC
Bus 380 VDC
Bus 48 VDC
Bus 24 VDC
Bus 12 VDC
Heat Circuit

Wulian Smart Home Devices

http://www.idclab.et.aau.dk
DFF project 2014-2016

Future Residential LVDC Power Distribution Architectures

International ranked research institutions

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

And the Danish Companies
Future Residential LVDC Power Distribution Architectures

International cooperation for DC power standards

LVDC Workshop SMB Strategic Group 4 on LVDC distribution systems up to 1500 V, 29th & 30th of September 2011, Dresden/Germany

380 VDC Workshop @ the 35rd IEEE INTELEC 17th October 2015, Hamburg/Germany

http://www.residentiallvdc.et.aau.dk
CPES: Hybrid AC-DC NanoGrid System

Future Energy Efficient Home/Building

- Solar panels (PV)
- Smart appliance
- Utility grid
- Plug-in Hybrid (PHEV)
- Energy Control Center (ECC)
- Energy Storage
- AC and Heating Ventilation...
- Wind Turbine

Different sources and loads are integrated with power electronics converters.

http://www.residentialvdc.et.aau.dk
Wind Turbine System

Wind Turbine atop the Whittemore Hall

Converter installation in the CPES' lab

175 V, 5-15 Hz

3.5 kW

Wind Turbine Dyno System

http://www.residentialvdc.et.aau.dk
CPES: Hybrid AC-DC NanoGrid System

Minimized System for Validation

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

- Generation
  - Solar, Wind;
  - FC, Generator;
  - ...

- Energy storage
  - Batteries;
  - CA, Flywheel;
  - ...

4. Load demand

2 X 5.2kW Electronic Load

DC bus 380V

- 10 kW
- 5 kW
- 3.5 kW
- 8.4 kW
- 3-6 kW

480V/240V
1-Φ, 60 Hz

ECC

Model 6203, 63204 shown.
Renewable Energy and Nanogrids (REN)

Work Scope

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

http://www.residentialvdc.et.aau.dk
Future Residential LVDC Power Distribution Architectures

Renewable Energy Park

Central Control

AC utility Mains

EV Charging Station

Communication network

380V

Washing machine

Electric Vehicles

Flywheels

48V

Refrigerators

Air conditioner

Supercaps

Electrolyzer

Fuel cell

Batteries

24V

Chargers

Ceiling fan

Led Lighting

Hydrogen tank

Hybrid Energy Storage Systems

High - Efficiency Household

http://www.residentiallvdc.et.aau.dk
ERANET project 2014-2016

Flexible electric vehicle charging infrastructure Flex –ChEV

http://www.flexchev.et.aau.dk
• 2 year experience in control design of IM based flywheel for grid ancillary services

• 2.2 kW expiremental test-bed has been built

• Fully modular control strategy based on distributed bus signalling -> scalable to units of different size

http://www.flexchev.et.aau.dk
Thank you for your attention!

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