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Smart Grids and Energy Markets

Future grid infrastructure
Field tests of LVDC distribution

Andrey Lana

CLEEN summit 2013, 12.6.2013

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Future grid infrastructure
Field tests of LVDC distribution

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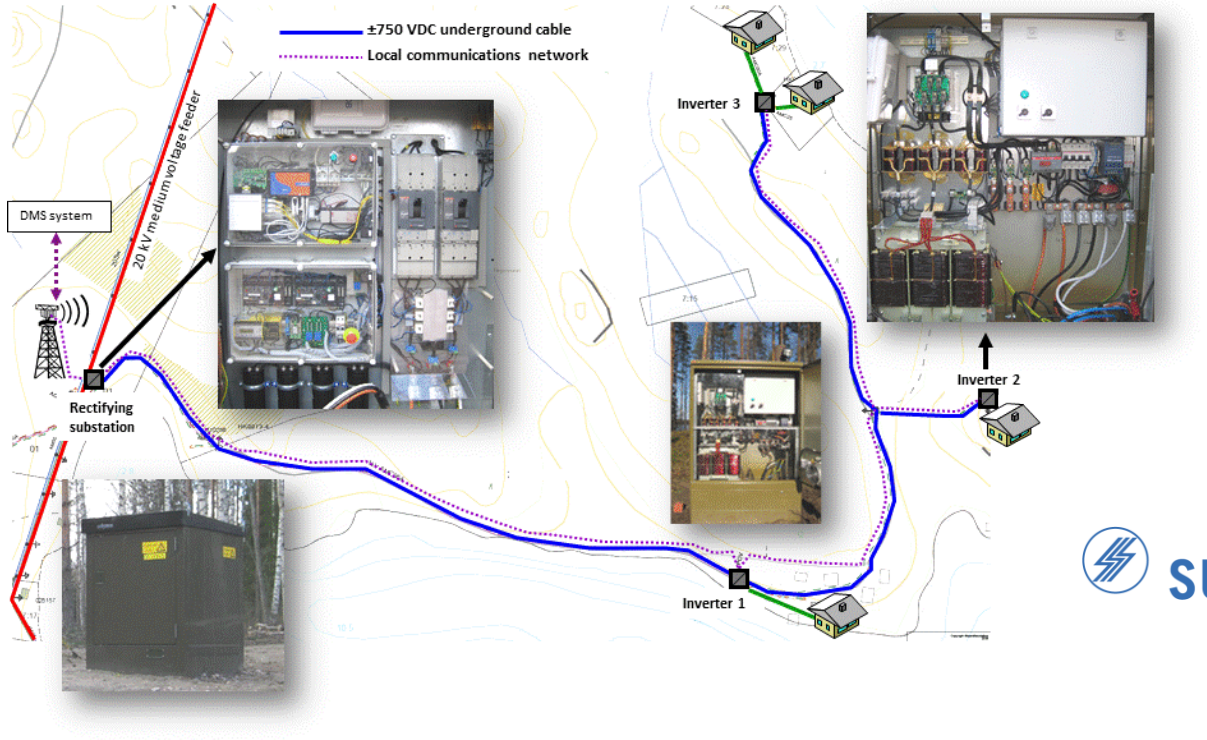

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Introduction to utility grid LVDC

- Background
  - Even though the Smart Grids is mainly development of intelligent applications and related ICT, the largest investments will be made to the primary electric infrastructure
- LVDC solution
  - Renaissance of “Edison's” direct current electric system based on modern power electronics
- Basic property
  - Improved technical performance compared to existing low voltage grid solutions – more power transfer with higher control in the same power lines
- Special feature
  - High penetration rate of intelligent hardware; thanks to power electronic converter technology – ready to use hardware for implementing smart applications
- Main philosophy
  - Replacing existing AC low voltage networks and parts of medium voltage grid with LVDC reduces the total costs of electricity distribution

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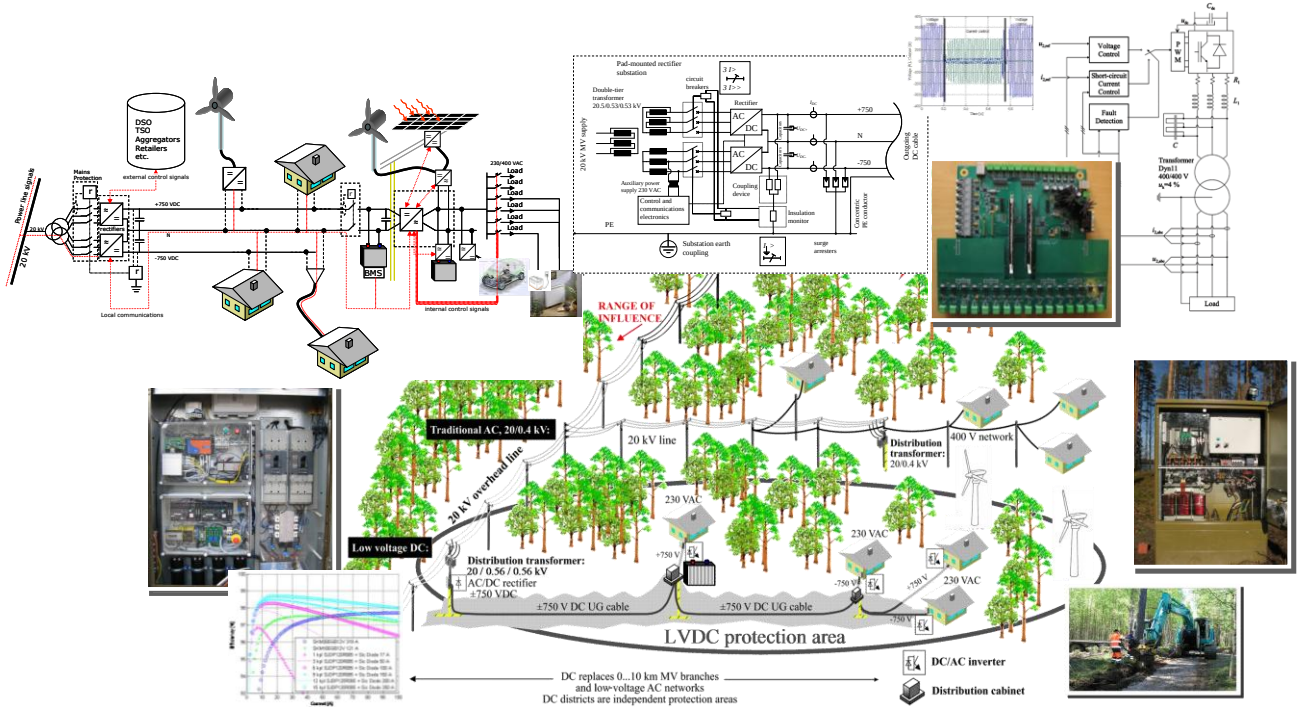
Hypothesis of LVDC Research

Power electronics and DC networks can reduce costs of power distribution, improve power quality and provide opportunity to integrate novel smart grid functionalities to power system and to support improvement of energy efficiency.



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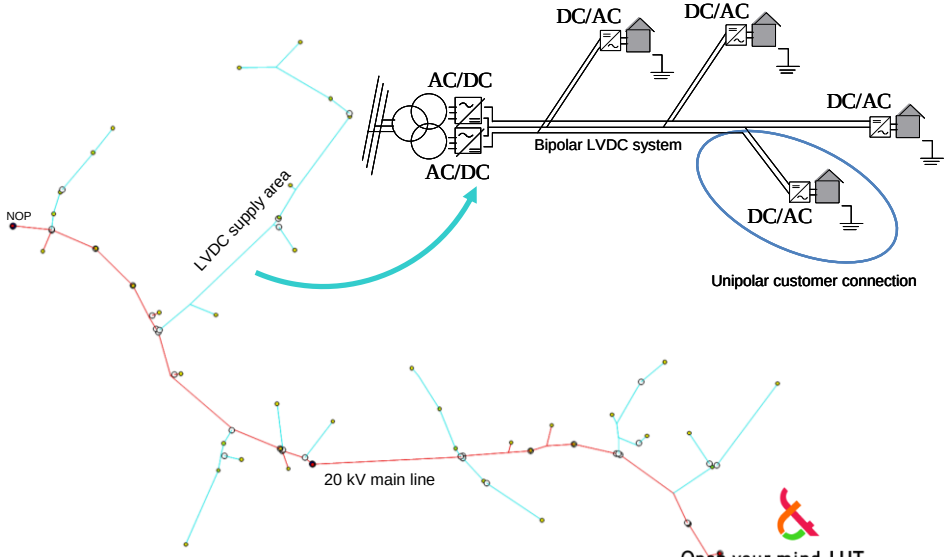
Concept of LVDC Electricity Distribution

- Rated voltage range
  - 75 – 1500 VDC (LVD 2006/95/EC)
  - 120 – 1500 VDC (IEC)
- An LVDC distribution system comprises power electronic converters and DC connection between the converters
  - The entire low-voltage network is realised with DC system
  - End-customers have either a direct DC connection, or an AC connection through a DC/AC inverter, or a DC connection through a step-down DC/DC converter
  - System comprises an integrated control and communications system

- LVDC system provides
  - Safe and reliable electric energy transmission from the MV network to the LV customers
  - Constantly good-quality voltage supply for customers
  - An easy-to-control connection point for small-scale generation units and storages
  - A ready-to-use platform for smart metering, demand management and network control



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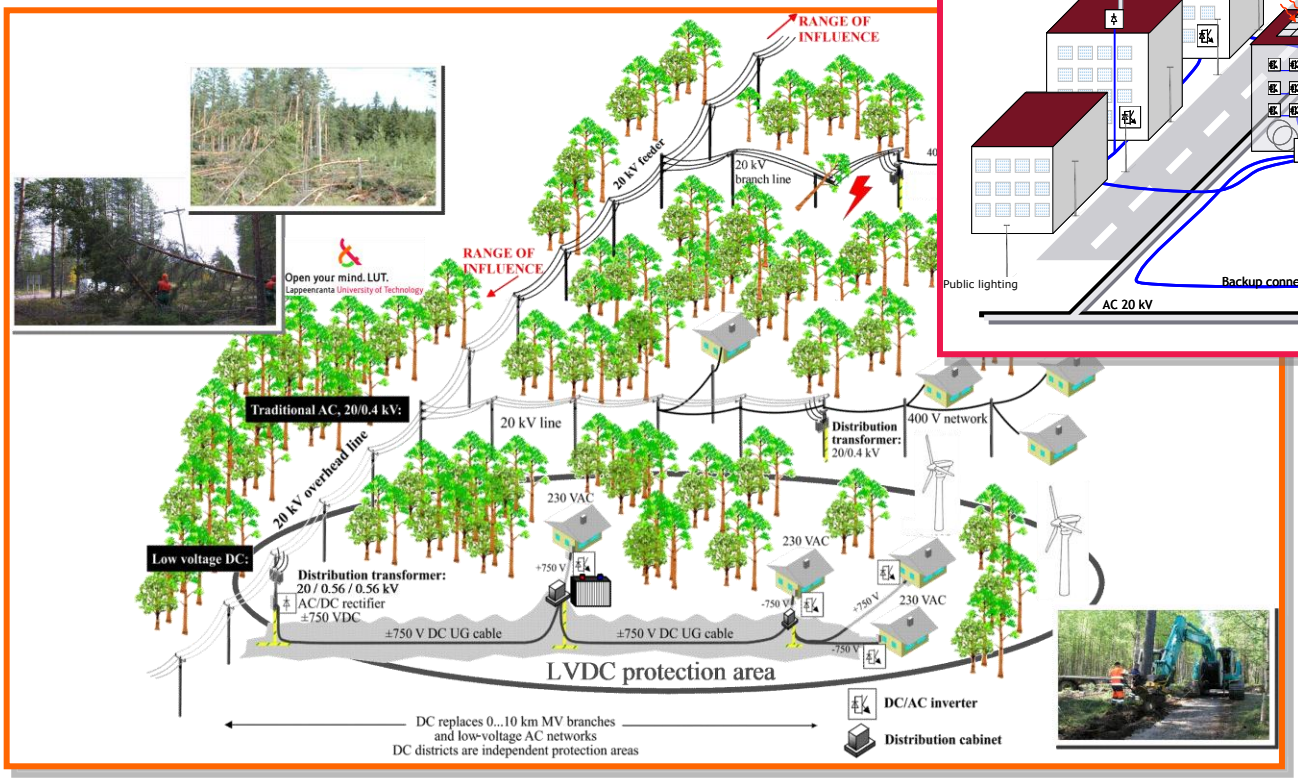
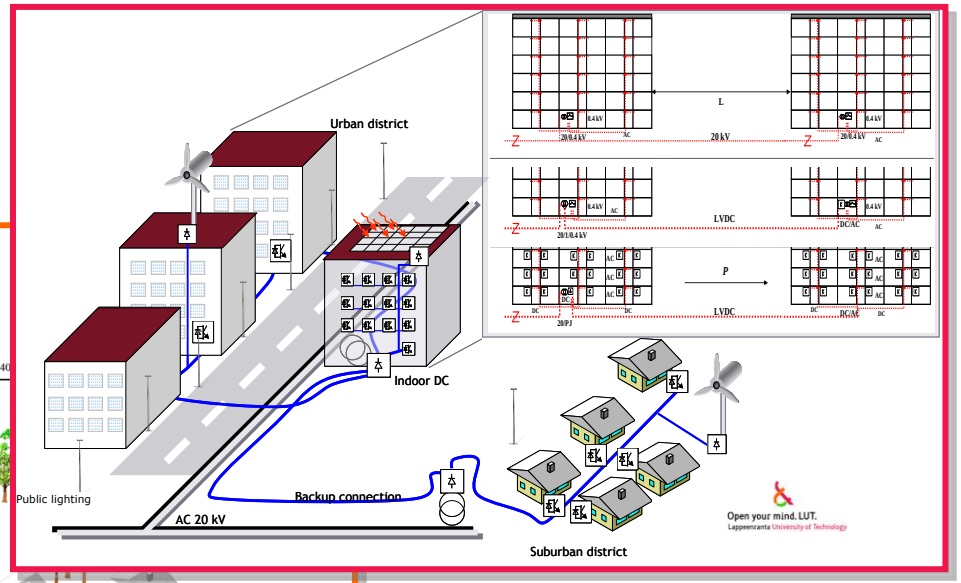
LVDC in Rural and Urban Environments





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Highlights – Research Platforms

- **Laboratory prototype**
  - Test environment for technical solutions, functionalities and design methods of LVDC technology
  - Study implementation of developed solutions in practical environment
  - Provide feedback for equipment development
    - Impact of environmental conditions
    - Requirements of installation and maintenance on equipment structures
    - Compatibility with interconnected systems and devices
  - Verification and development of system design, control algorithms and management systems
- **Real-life network environment**
  - Durability and reliability of electronic components in demanding distribution network environment
  - Inspections of installations and authorised approvals of structures
    - Verification of electrical safety
    - Equipment ratings
    - Documentation
  - Experiences from electricity end-users and from installations and operations personnel
  - Practical experiences to support LVDC system standardisation

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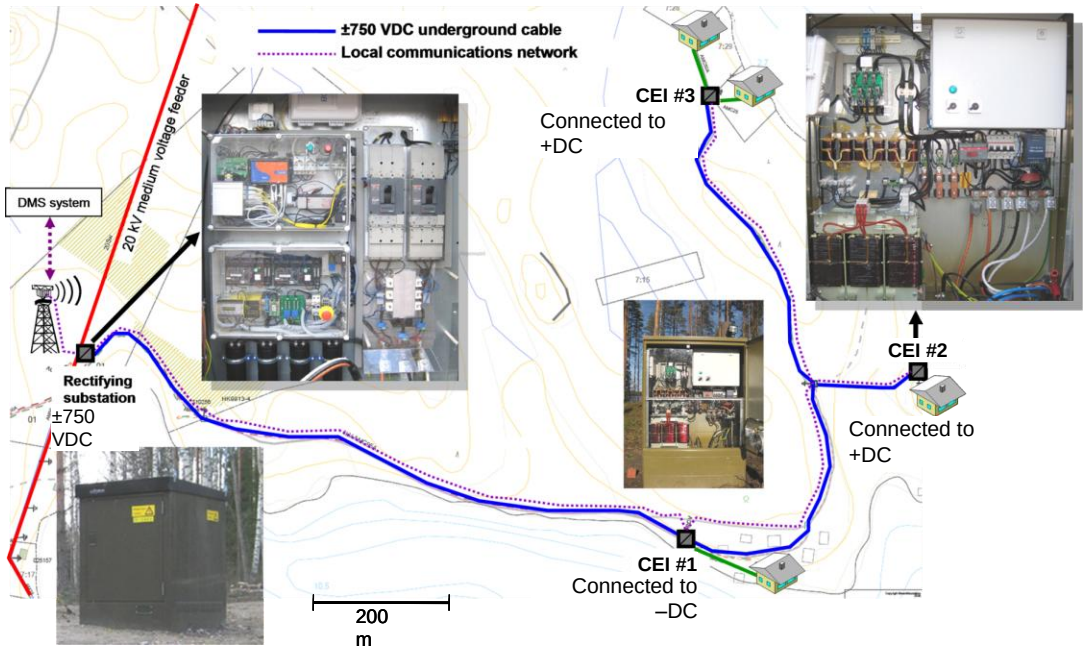
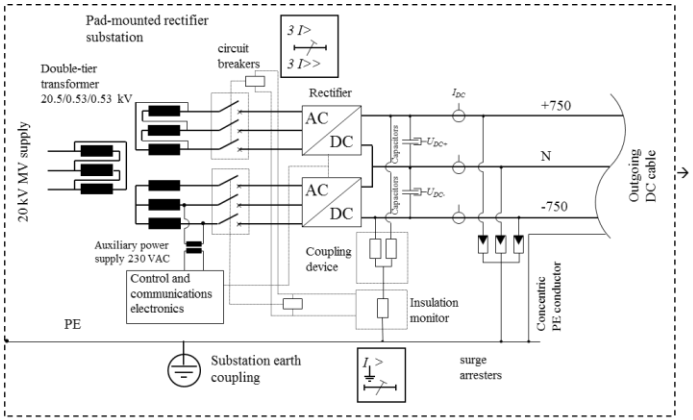
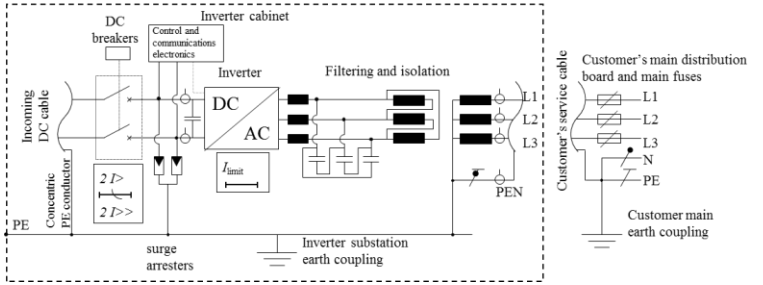
Field tests of LVDC distribution by LUT and SSS Oy

- 1.7 km bipolar LVDC network with three three-phase customer-end inverters supplying four residential houses installed in Suomenniemi
- Objective to test converter technology and collect experiences from LVDC distribution
- Continuous 24/7 operation during June 2012 – May 2013







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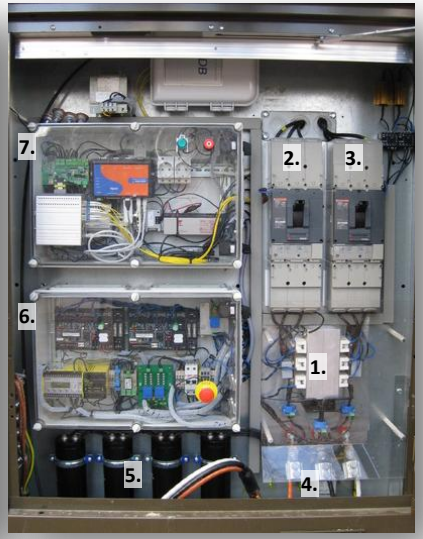
Field Installations by LUT and SSS Oy

Fully customisable hardware and software platform for research purposes. Comply with national and IEC electrical safety requirements.



1. Half-controlled thyristor rectifier
2. -750 V side moulded-case circuit breaker
3. +750 V side moulded-case circuit breaker
4. DC network surge protectors
5. DC network capacitors
6. Thyristor control, insulation monitoring, and measurements
7. Rectifier control, embedded PC, and communications

1. DC supply bus
2. Common-mode choke
3. DC network surge protector
4. Electronics power supply
5. DC circuit breaker
6. Capacitor
7. Power electronics (IGBT)
8. Output filter
9. Output isolation transformer
10. Output bus

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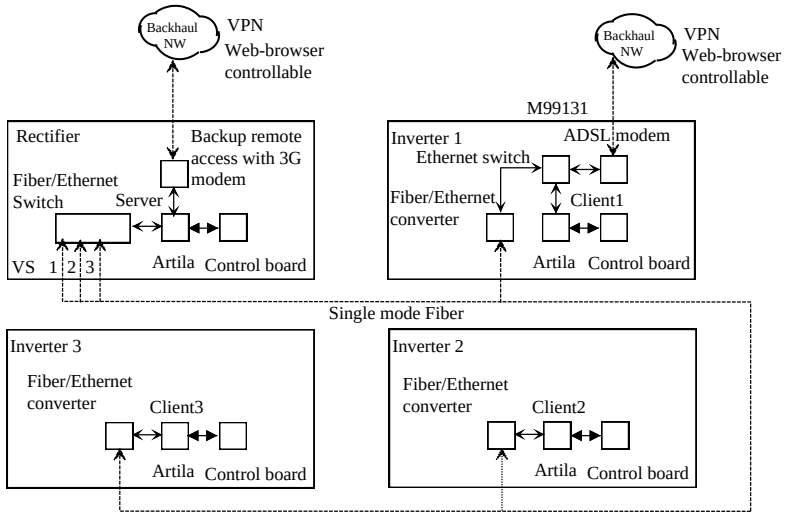
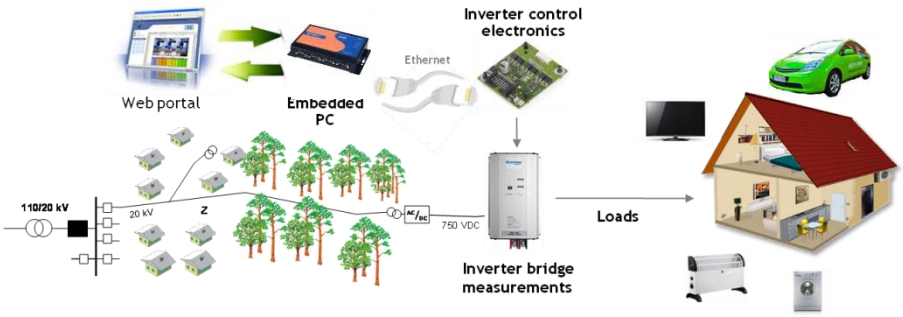
System Management

Web portal for monitoring and control



Local ICT-system



Examples of measurements and warnings (fault codes) during July 2012 thunderstorm.

System Management

- Control functions
  - Rectifier control, i.e. DC network start-up and shutdown
  - Remote emergency shutdown of the system
  - Customer-end inverter (CEI) control (start-up, shutdown, reset)
- Real-time monitoring, rectifier
  - DC network voltages and currents
  - Rectifier power electronics temperature
  - DC network isolation resistance
- Real-time monitoring, customer-end inverter
  - DC voltage and current
  - Customer-end phase voltages and currents
  - Control electronics supply voltage and system temperatures (cabinet and power electronics)
  - Customer-end frequency
- Fault situations
  - Fault code display and reset
  - Alarm reporting
  - Recording of high-resolution waveforms before and after fault (“black box” operation)
- Logging
  - 1 minute resolution data (maximum, minimum and mean values for powerflow, voltages and currents)
  - Customer power quality data (currently with 16 seconds interval)
  - Customer voltage and current harmonic content (1 minute interval snapshots)
  - Network insulation measurements
  - Faults and system events

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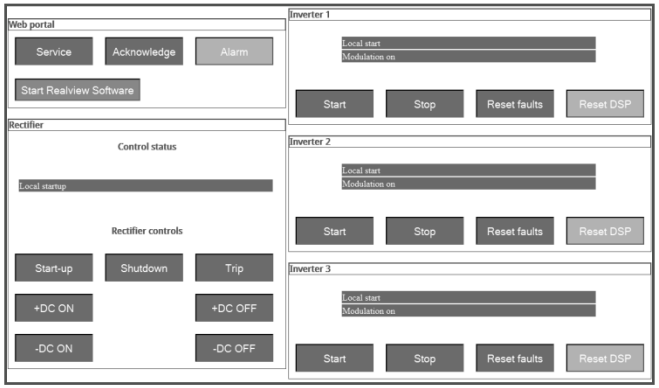
System Management

Embedded ICT system

- Remote supervision and management system providing web-based portal with high-resolution measurements, logging, fault identification and event recorder
- Power quality analyser functions (IEEE Std 1459-2010)



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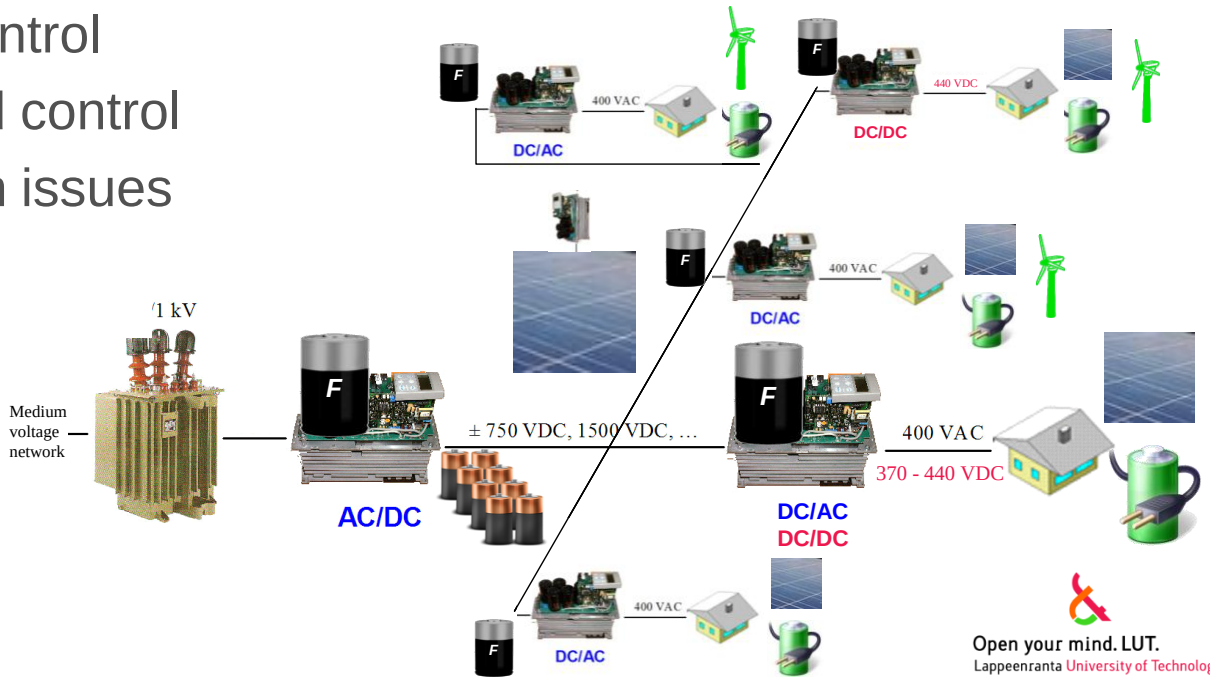
Conclusions on field tests of LVDC distribution

- First implementation of modern LVDC distribution and CEI based supply in continuous use by a DSO
- Very reliable, though it is a *research setup*
- Special situations have been managed as planned
- Quality of supply has been high, but there is still room for improving the control algorithms
- Platform for further development of smart grid functionalities

Field Installations - Next steps

- Continuous collection of user experiences
- Updates to converter hardware and system controls
- Connection of energy storages and local generation
- Integration of microgrid controls
- Island mode control
- Market oriented control
- Standardization issues



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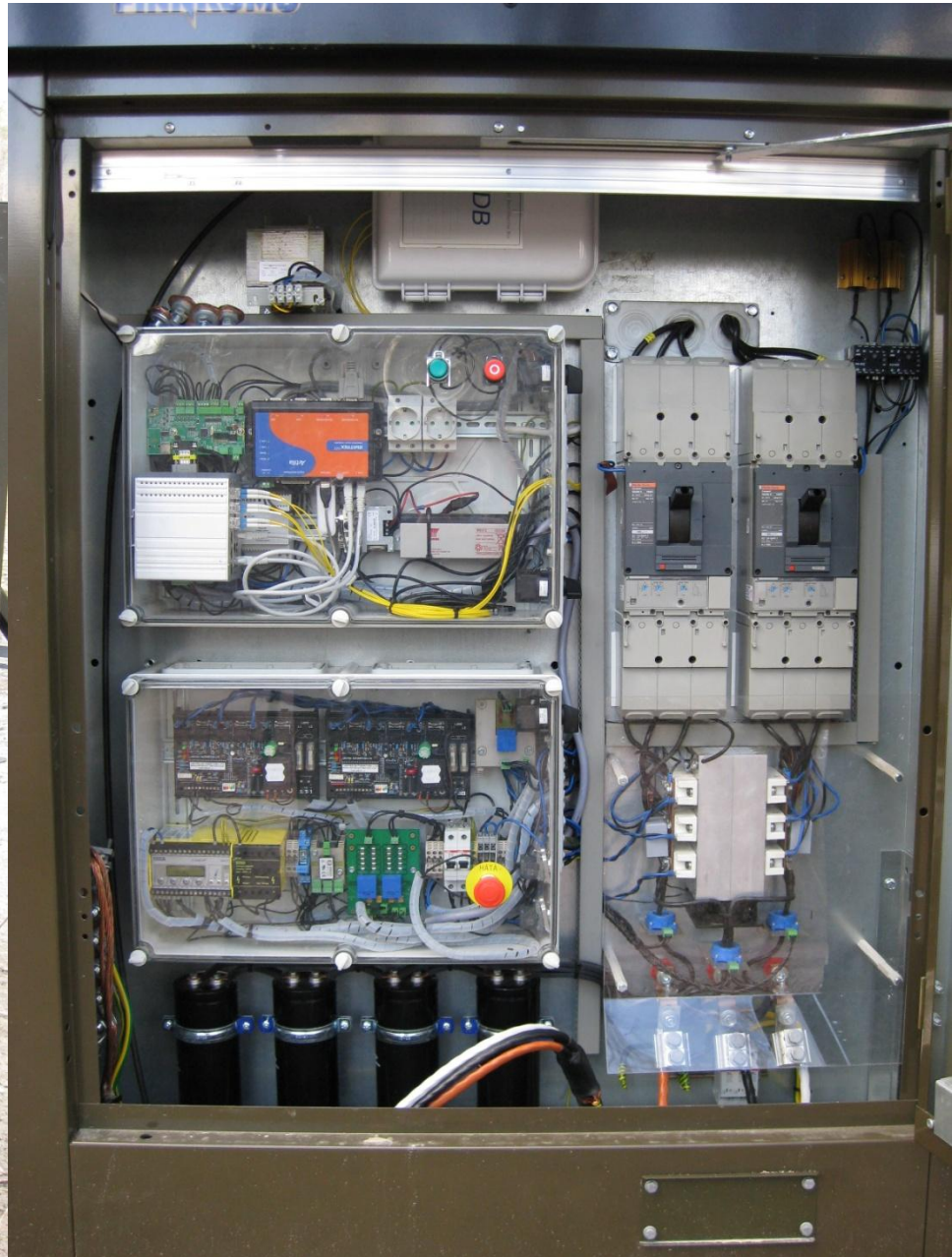
Rectifying Substation

Double-Tier Transformer and Rectifier



CEI #3 and CEI Control Electronics

Rectifier Testing

First System Start-Up and CEI Tests

First System Start-Up and CEI Tests

RF EMI Measurements

PLC Communications Measurements

Winter 2012-2013

Researcher Exercising in February 2013