CLEEN
Cluster for Energy and Environment

sgem
Smart Grids and Energy Markets

Open your mind. LUT.

Lappeenranta University of Technology

Open your mind. LUT.
Lappeenranta University of Technology

Converters and power electronics

Pasi Nuutinen

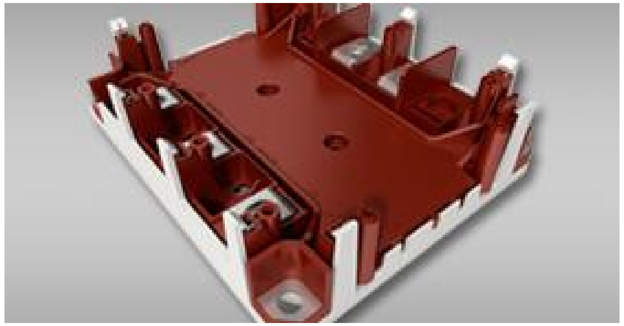
Pasi Peltoniemi

Institute of LUT Energy

Energy Technology | Electrical Engineering | Environment Technology

Motivation to use power electronics

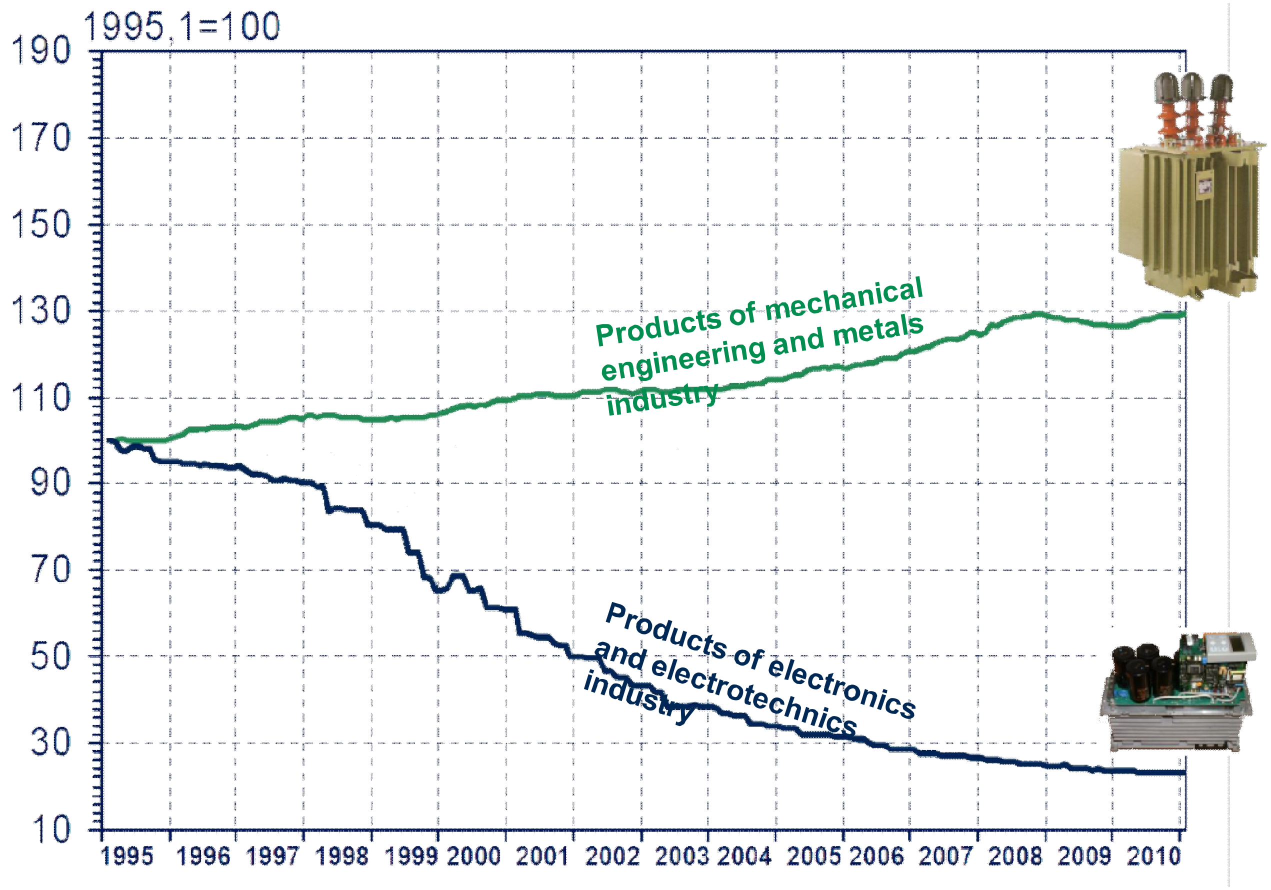
- Product prices of mechanical industry have increased
- Product prices of electronics industry have decreased
- Power electronics enables more accurate power quality control
- Smart Grid functions are possible to achieve with intelligent power electronics
- Power electronics makes LVDC distribution possible
- In some cases, energy efficiency and reliability of the distribution networks can be improved



Source: Semikron GmbH

Price development of power electronics

Development of producer prices in technology industries in Finland



Source: Statistics Finland

Product prices of conventional metals and mechanical industry have increased in average 2 % annually. The increase was rapid between years 2003 and 2009, achieving value of 4 %/a. The economical recession stopped the increase of product prices on the level of 2009

Product prices of electronics industry have decreased in average 5 % annually. The decrease have slowed down during past three years to the level of 1-2 %/a. Despite of healing from the recession product prices decreased about 0.5 % during year 2010

Future trends of crucial properties of power electronic system components

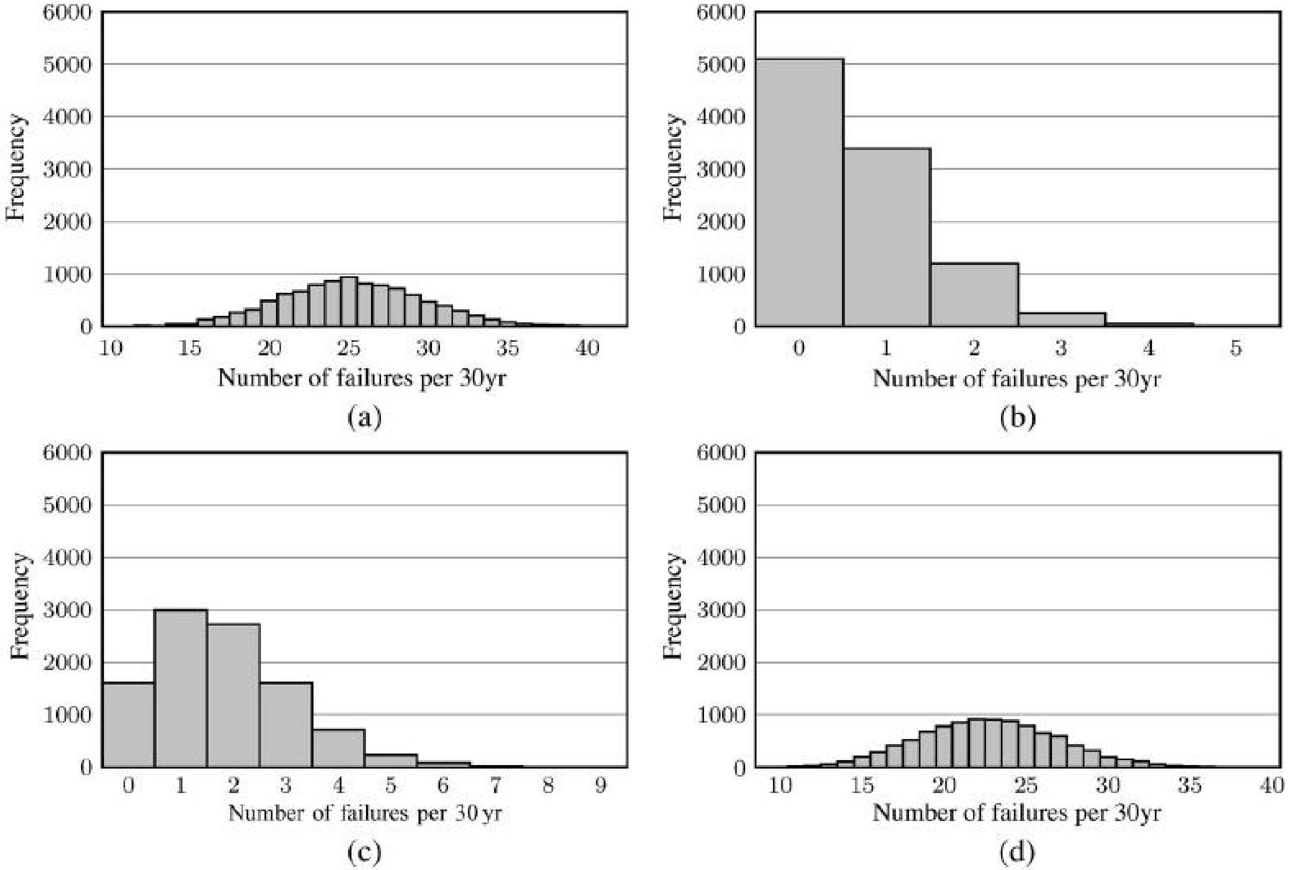
- Power electronic switches:
  - Materials used to build the power electronic switches, such as SiC and GaN have shown to possess the needed properties to improve the energy efficiency and reliability of power electronic devices.
  - However, the penetration of SiC-based switches to the market has been the topic for almost two decades already.
  - Now, GaN-based switches are already available. However they are only available for low-voltage (12 V) and low current (30 A) applications.

- Filters:
  - Materials such as ferrite and amorphous cores are available in the market.
  - Current trend is to use SiFe cores that concludes to either bulky filter cores or high losses.
  - The development of power electronic switches also makes the passive filter design easier with respect to allowed losses and voltage (and current) distortion.

Reliability of power electronics

- Reliability of power electronics has an significant effect on feasibility of the use of power electronics in electricity distribution
- If compared with traditional network components (transformers etc.), the reliability is worse
  - MTBF of a complete converter is years
  - MTBF of a transformer is decades
- Manufacturers are usually reluctant to deliver failure rates of their products
- Maintenance program provided by the manufacturer is based on calculated reliability values and practical experience
- Components in power electronic device are usually considered in series → failure of any component causes system failure

Reliability of power electronics

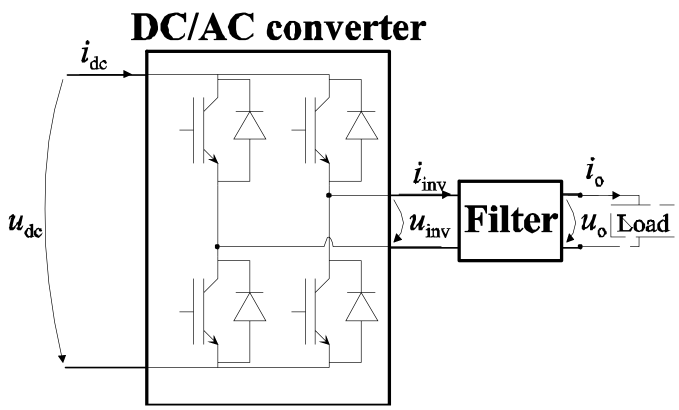


Distribution of failures per inverter modeled over 30-year service life with 10 000 samples. (a) Total failures. (b) Fan failures. (c) IGBT failures. (d) Capacitor failures. [Ristow 2008]

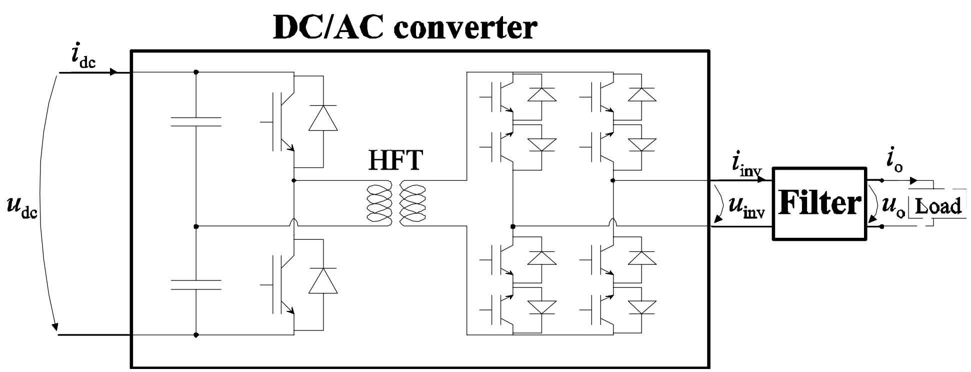
Converter structures – single-phase

Open your mind. LUT.
Lappeenranta University of Technology

- Applicability of different converter structures has been evaluated
  - Two-level half-bridge and full-bridge
  - Three-level NPC (neutral point clamped)
    - Three-level inverters are studied in more detail at TUT
  - High-frequency-link integral-half-cycle (HFL-IHC) converter
- Full-bridge proved to be the most suitable solution for single-phase LVDC customer-end system, when galvanic isolation is not needed
  - Full-bridge inverter has been mainly researched
- When galvanic isolation is needed, HFL-IHC is a suitable option to be used
  - Structure includes high-frequency transformer (HFT)
  - 50 Hz transformer is not reasonable solution because the size and costs



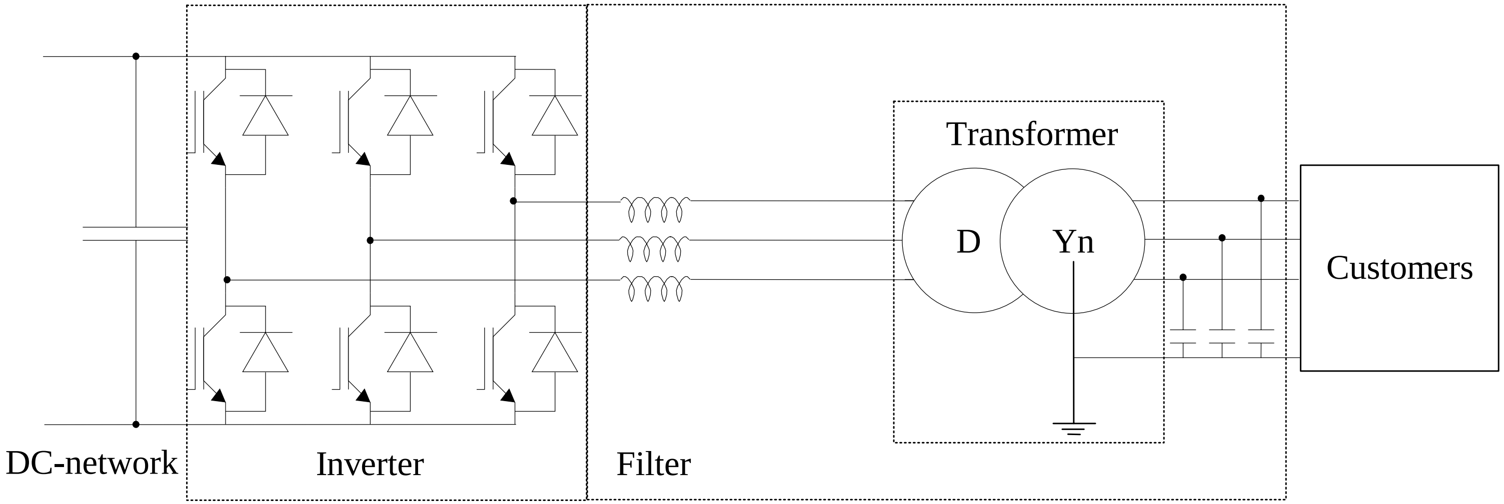
Full-bridge



HFL-IHC

Converter structures – three-phase

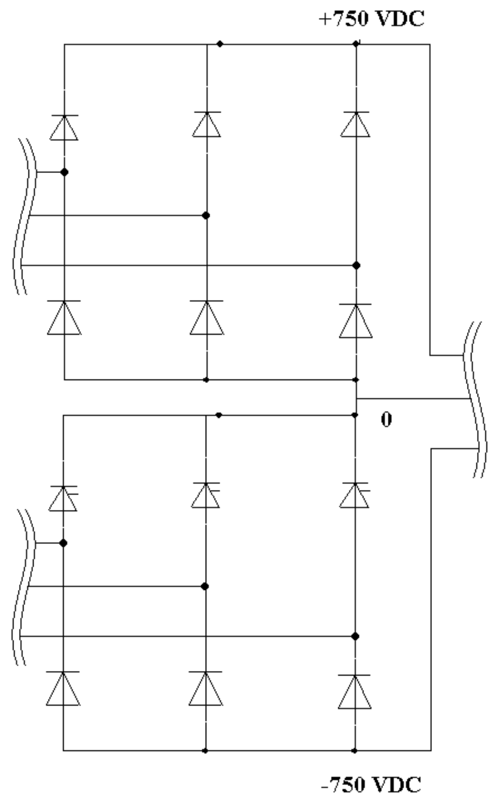
- Only two-level solution (figure below) is investigated.
- Similar control system can be used as with single-phase applications
  - A major difference in single-phase and three-phase solution is that unsymmetricity compensation is needed in three-phase solution.



Three-phase solution with transformer for galvanic isolation

Converter structures – rectifier

- Controlled and uncontrolled structures have been evaluated
  - Diode bridge, thyristor bridge and PWM rectifier
- Unidirectional power transmission has been mainly researched
  - Use of diode and half-controlled thyristor bridge rectifiers are studied in more detail
- The start-up of the network requires controlled rectifier [Nuutinen 2011]
  - Network capacitances take high charging current
  - Network inductances can cause customer-end overvoltages
- The LVDC network requires no DC voltage control in normal operation
- Requirements
  - Short-circuit current supply capability



6-pulse diode bridge and 6-pulse half-controlled thyristor bridge rectifier

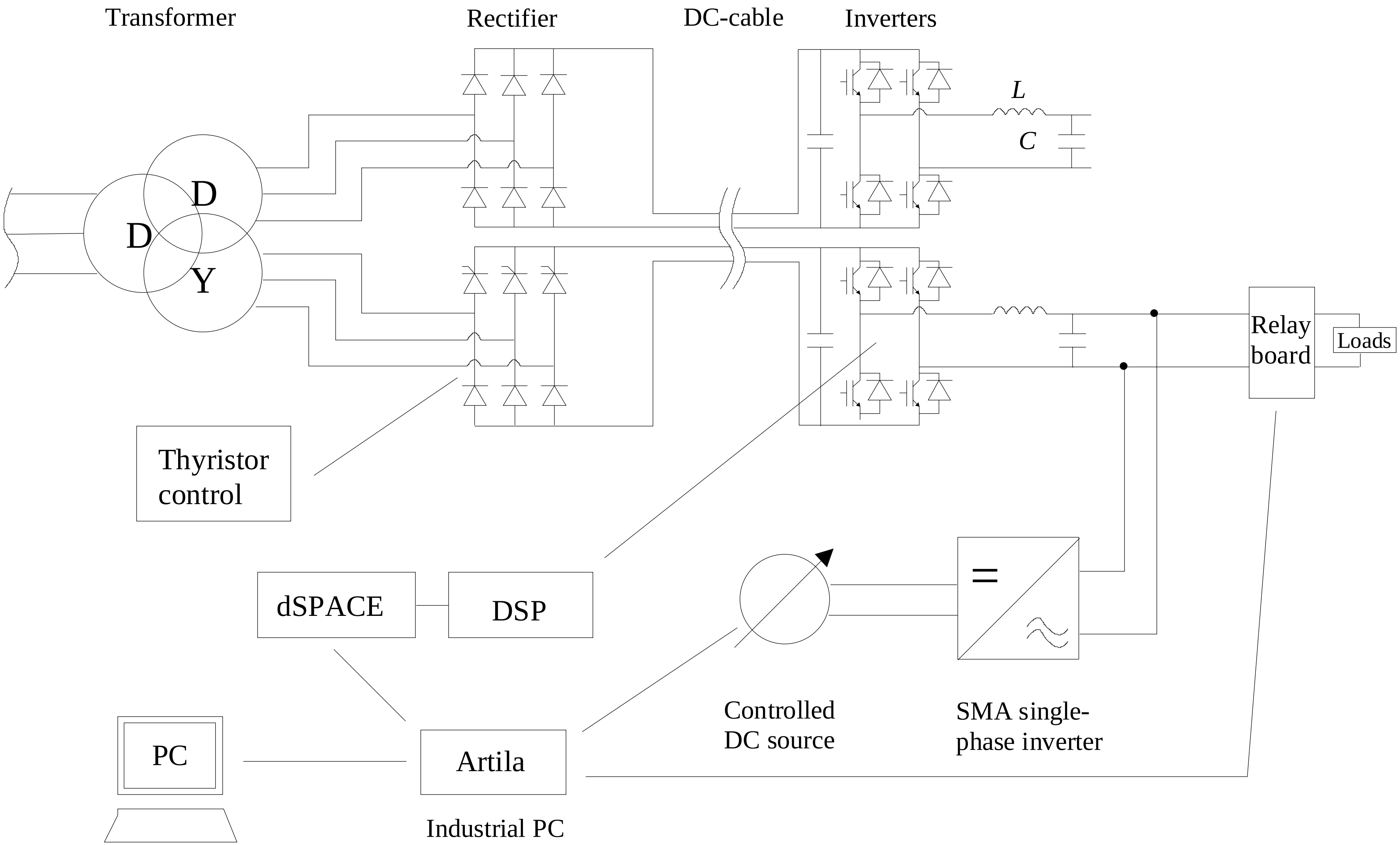
Passive filters

- Background: Losses produced by the passive filter have major impact on the energy efficiency of the total system. Solutions currently applied are not viable for power distribution purposes.
- Goal: Minimizing the life-cycle costs of the customer-end system also means minimizing the filter losses when known technical restrictions are present.
- Challenge: In power electronic system the worst-case operation for filter is usually in no-load where effective frequency of the output current is at first switching frequency.
  - Due to the high-frequencies appearing in no-load typical materials such as silicon-iron have poor properties and lead to bulky and low-efficiency structures.
- Solution: Materials with better frequency properties such as amorphous metal ($S_n \approx 2$ – tens of kVAs) and ferrites ($S_n < 2$ kVA) are more suitable for power electronic converter. [Peltoniemi 2010]
  - Using ferrites becomes attractive when highly distributed or decentralized converter units are used. That is, a converter unit consists of various lower power level converter which supply the load.

Control of output voltage

- Goal: To meet the requirements set in standard EN50160 for the phase voltage.
- Challenge: Control algorithm needs to operate as wanted with any type of load. In three-phase applications are not equally loaded at any time.
- Solution: Observer-based control algorithm is used. To improve control algorithms performance and stability; certain amount of adaptivity can be introduced. [Peltoniemi 2010]
  - When the process is known a gain-scheduling-based adaptive algorithm can be used.
  - To make the control algorithm compatible with both 1- and 3-phase solutions a synchronous co-ordinate based solution is used.
  - In 1-phase systems, the synchronuous co-ordinate is created virtually.
  - In three-phase application voltage unsymmetry compensation is needed.

Structure of the laboratory prototype

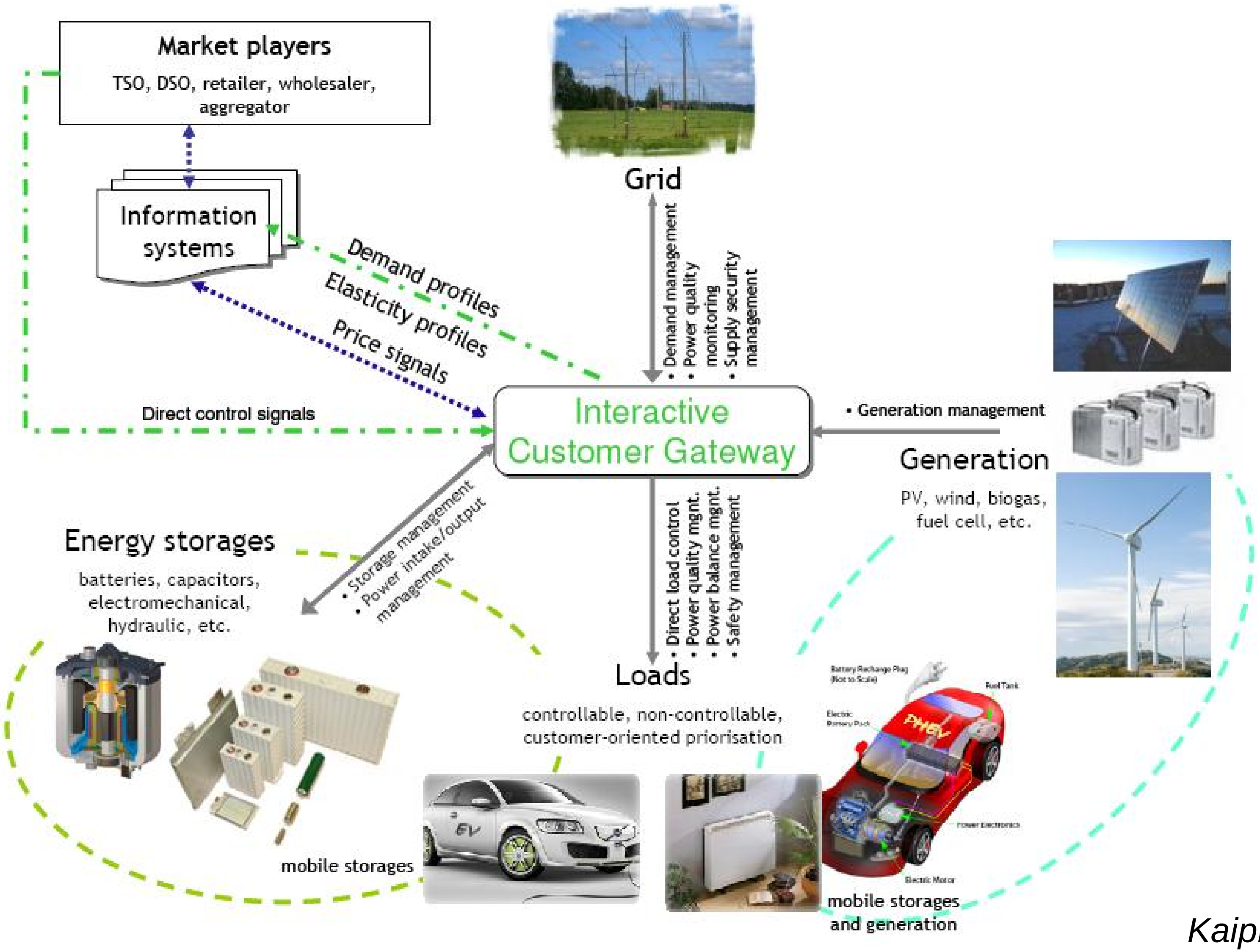


Laboratory prototype – specifications

Open your mind. LUT.
Lappeenranta University of Technology

- 6-pulse diode bridge and 6-pulse half-controlled thyristor bridge rectifiers
- 200 m DC cable, AXMK 4x16
- Two single-phase inverters
  - Second inverter is used only if two-inverter operation is needed
- No galvanic isolation, IT network
- IGBT modules: Semikron, maximum current 160 A (inverter 1) and 75 A (inverter 2)
- Control electronics
  - Texas Instruments TMS320F2811 digital signal processor control board (2 pcs)
  - dSPACE DS1005 control environment
- SMA Hydro Boy 1 kVA converter
- Serial bus controlled DC power supply
- Serial bus controlled relay board
- Seven contactors for resistive load control
- Artila Matrix 512 embedded PC for higher level control and data communications
- Required protection devices and contactors for fault testing

Principle of the interactive customer gateway



Kaipia 2010

Interactive customer gateway functions in laboratory prototype

Open your mind. LUT.
Lappeenranta University of Technology

- Transmission of power measurement data
- Transmission of control reserve data
- Limiting of grid power feed (grid → customer)
- Limiting of grid power feed (customer → grid)
- Modeling of network load
- Prediction of network load
- Modeling of control reserve
- Prediction of control reserve
- Distribution fee signal receiving
- Fault detection and alarms
- Disconnection from faulty network
- Island detection
- Fault recording
- Contact voltage measurement
- Voltage waveform monitoring
- Voltage level correction
- Voltage distortion filtering

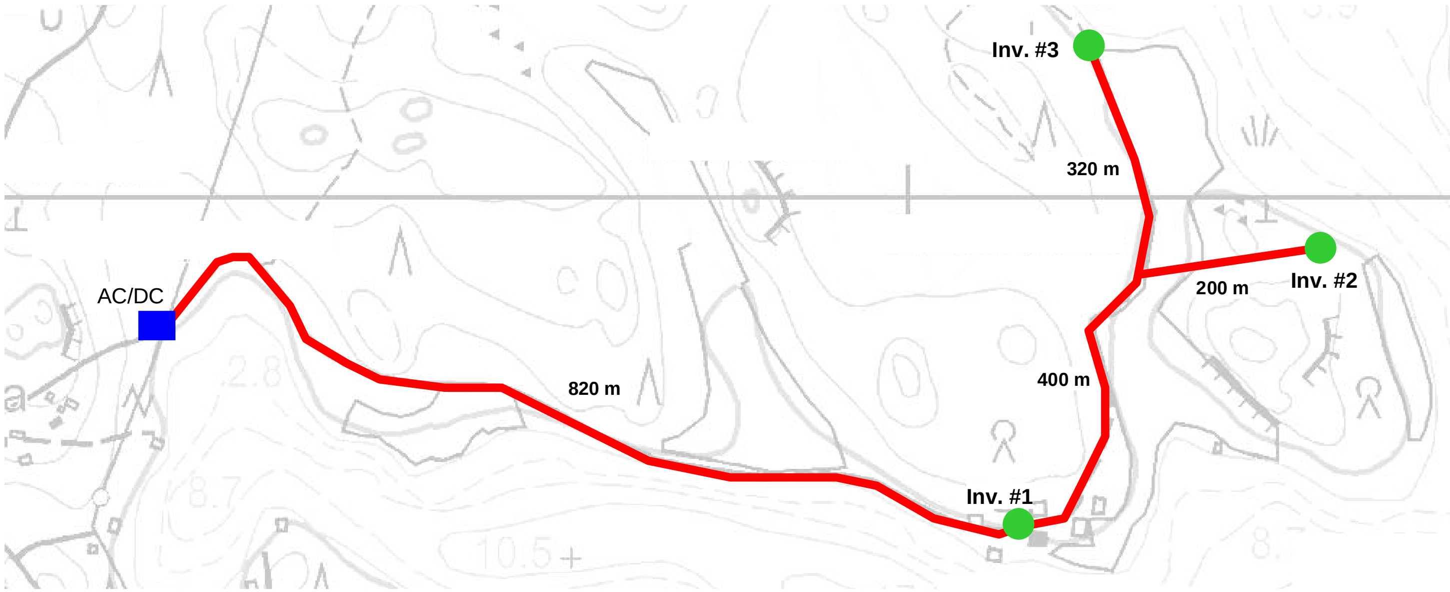
- ❑ Implemented
- ❑ Partly implemented
- ❑ Not implemented

INCA 2010

Real-environment research platform

Open your mind. LUT.
Lappeenranta University of Technology

- Provides real environment to implement and test LVDC system
- DC network and customer-end voltage and current measurements
- Fast data communications between inverters and rectifier
- Data communications and memory make data logging possible
- Powerful control electronics enables implementation of some interactive customer gateway functions
- Co-effort of Suur-Savon Sähkö Ltd. and LUT



Real-environment research platform components

Open your mind. LUT.
Lappeenranta University of Technology

- Double tier transformer
  - Voltage: 20/0.562/0.562 kV
  - Power: 100/50/50 kVA
- Two 6-pulse half-controlled thyristor bridge rectifiers
- Bipolar DC cable
  - Voltage: ±700 VDC
- Three three-phase inverters
  - Power: 16 kVA each
  - Four customers, one inverter supplies two customers
  - Galvanic isolation with 16 kVA 50 Hz transformers
- Optical fiber data connection between rectifier and inverters
- Embedded PC at every inverter and rectifier
- Remote monitoring

Real-environment research platform – rectifier

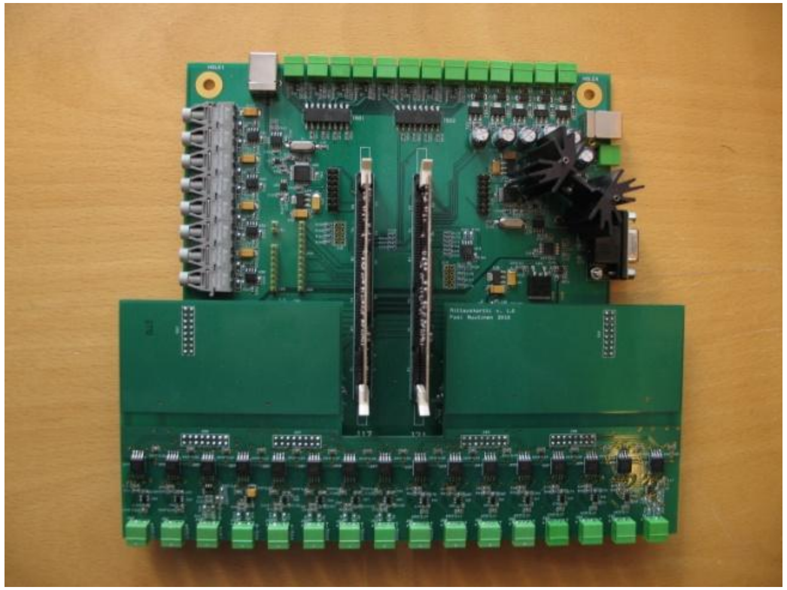
Open your mind. LUT.
Lappeenranta University of Technology

- Two 6-pulse half-controlled thyristor bridges
  - Both bridges are individually controlled

- Components
  - Thyristor modules: 137 A Semikron SKKH 132/08
  - Thyristor controller: United Automation FC36M (2 pcs)
  - Control electronics
    - Atmel ATMega 48V microcontroller
    - DC current measurement (3 pcs)
    - DC voltage measurement (2 pcs)
    - General outputs (6 pcs)
    - General inputs (4 pcs)
    - RS-232 and USB ports
  - Artila Matrix 512 embedded PC for higher level control and data communications

Real-environment research platform – inverters

- Three-phase inverters, can be connected to existing network without changes
- Isolation transformer and grounded customer network
- IGBT modules: 330 A Semikron SKiM 400GD126DM
  - Designed to supply at least 250 A_{RMS} short-circuit current
- Isolation transformer: 16 kVA, 400/400 V, Dyn11
- Control electronics
  - Texas Instruments TMS320F28335 digital signal processor (2 pcs)
  - Measurements
    - Transformer secondary voltages (3 pcs)
    - DC voltage
    - DC current
    - Transformer secondary currents (6 pcs, low and high current range)
    - Neutral current
    - Transformer secondary sum current
    - IGBT temperature
    - Two additional voltage measurements
  - 8 optical gate drive outputs
  - Two USB ports (programming and data transfer, DSP 1 and DSP 2)
  - RS-232 port
  - Ethernet
  - SD memory card slot
  - Open collector outputs (5 pcs)
  - Optoisolated external interrupts (8 pcs)
  - Battery undervoltage disconnection
- Artila Matrix 512 embedded PC for higher level control and data commucations



Research

- Inverters
  - Common-mode interferences in both galvanically isolated and non-isolated system
  - Radiating interferences
  - Electrical safety in non-isolated system
  - Converter energy efficiency in different operating conditions
    - Filter and power electronics
  - Customer-end inverter structure
    - Size, number, topology
  - Reliability of power electronics
  - Possibility of embedding protection devices to the converter
  - Control algorithm development (single-phase and three-phase)

- Rectifier
  - Start-up operation and especially operation after high-speed auto-reclosing
  - Bidirectional power transmission

References

Open your mind. LUT.
Lappeenranta University of Technology

[Nuutinen 2011] Nuutinen, P., Kaipia, T., Lana, A., Silventoinen, P. *Start-up of the LVDC Distribution network,* CIRED2011 21st International Conference on Electricity Distribution, 2011.

[Peltoniemi 2010] Peltoniemi, P. *Phase voltage control and filtering in a converter-fed single-phase customer-end system of the LVDC distribution network,* Acta Universitatis Lappeenrantaensis 404, doctoral dissertation, 2010.

[Kaipia 2010] Kaipia, T., Partanen, J., Järventausta, P. *Concept of Interactive Customer Gateway*, research report, LUT Energy, 2010.

[INCA 2010] Järventausta et al. *INCA - Interaktiivinen asiakasliityntä ja sen hyödyntäminen sähköjärjestelmän hallinnassa ja energiatehokkuuteen kannustavissa palveluissa*, project report, 2010.

[Ristow 2008] Ristow, A., Becowić, M., Pregelj, A. *Development Of A Methodology For Improving Photovoltaic Inverter Reliability,* IEEE Transactions on Industrial Electronics, Vol. 55, no. 7, July 2008

Open your mind. LUT.

Lappeenranta University of Technology

Institute of LUT Energy

Energy Technology | Electrical Engineering | Environment Technology