CLEEN
Cluster for Energy and Environment

Open your mind. LUT.
Lappeenranta University of Technology

Low voltage DC distribution

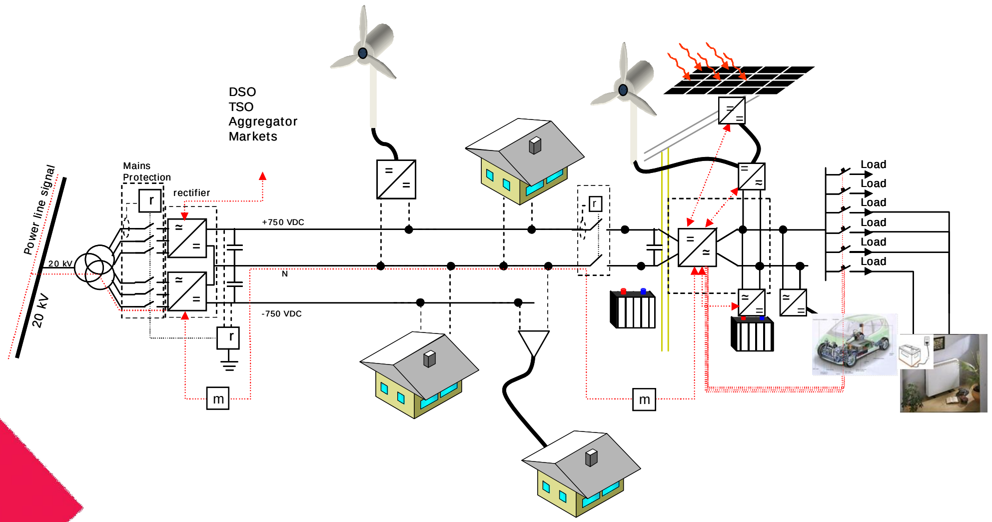
sgem
Smart Grids and Energy Markets

Concept and technology overview

Tero Kaipia
Pasi Nuutinen
Pasi Salonen
Pasi Peltoniemi
Andrey Lana
Antti Pinomaa

Development of LVDC distribution system

Concept and technology overview



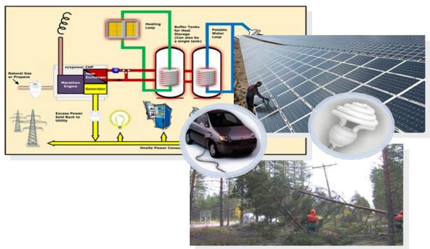
Tero Kaipia
Pasi Nuutinen
Pasi Salonen
Pasi Peltoniemi
Andrey Lana
Antti Pinomaa

Development drivers

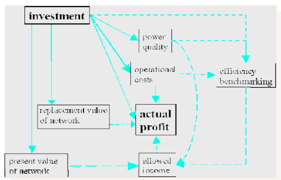
Environment
- Climate change
- Landscape issues
- Land-use issues
- Impregnants
- Electric and magnetic fields

Energy policies
- Legislation
- Energy efficiency objectives
- Reduction of emissions and oil dependency
  - Renewables, DG and EVs
  - Demand response

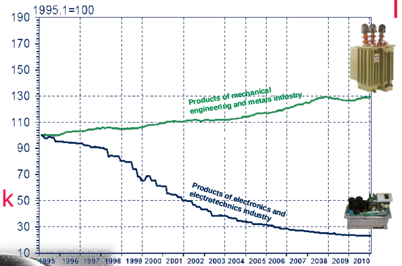
Society and socio-economics
- Safe use of electricity
- Reasonable pricing
- Supply security
- Energy efficiency actions
- Functional markets



Utility stake holders
- Profit expectations
- Predictable rules
- Company image
- Consolidation



Network infrastructure and assets
- Aging infrastructure
- Allowed profit regulation
- Revenue expectations of owners
- Supply quality expectations
- Major disturbance vulnerability
- Increasing prices of conventional network components
- Decreasing prices of emerging technologies



Customers
- Customer expectations on
  - Quality of supply
  - Pricing
  - Functional markets
- Changes in energy usage patterns
  - Energy efficiency actions
  - Dynamic loads
  - EVs and DG
- Equality
  - pricing
  - service quality

Power Quality
- Security of supply
- EMI and EMC, distortion
- Sensitivity of system and load appliances

Regulation of network business
- Allowed profit regulation
- Quality of supply
- Cost efficiency
- Energy efficiency

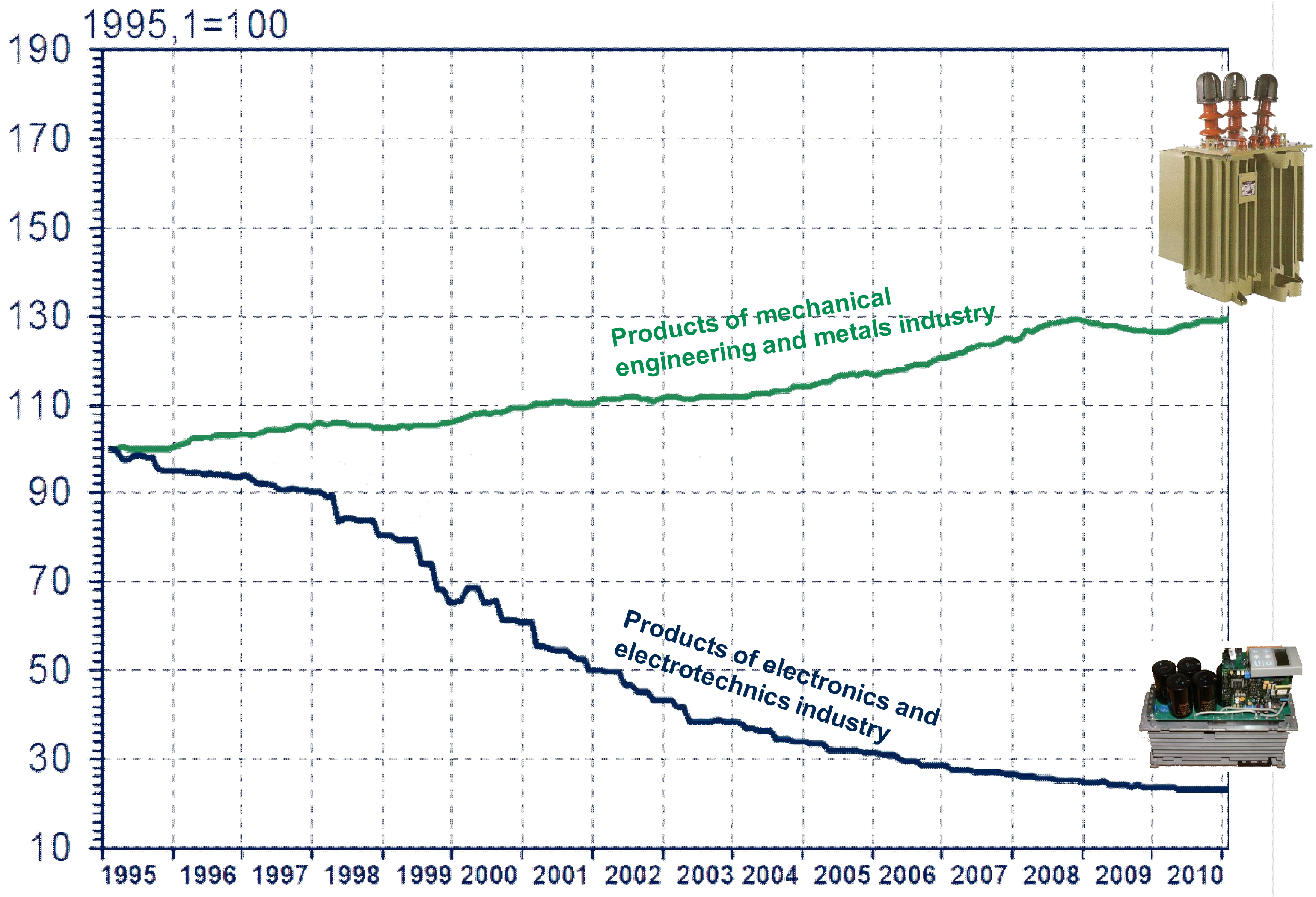
Technical development
- Automation and communication techniques
- DG and energy storages
- Building automation
- Underground cabling
- Power electronics
- Distributed intelligence
- Preventive maintenance techniques
- Software development

Role of power electronics in future electricity distribution infrastructure

Recourses and competences
- Human resources
- Outsourcing
- Tools and methods to aid decision making

Smart Grid visions
- Self healing and proactive power system
- Market and grid oriented system control
- No market limitations

Price index of industrial products

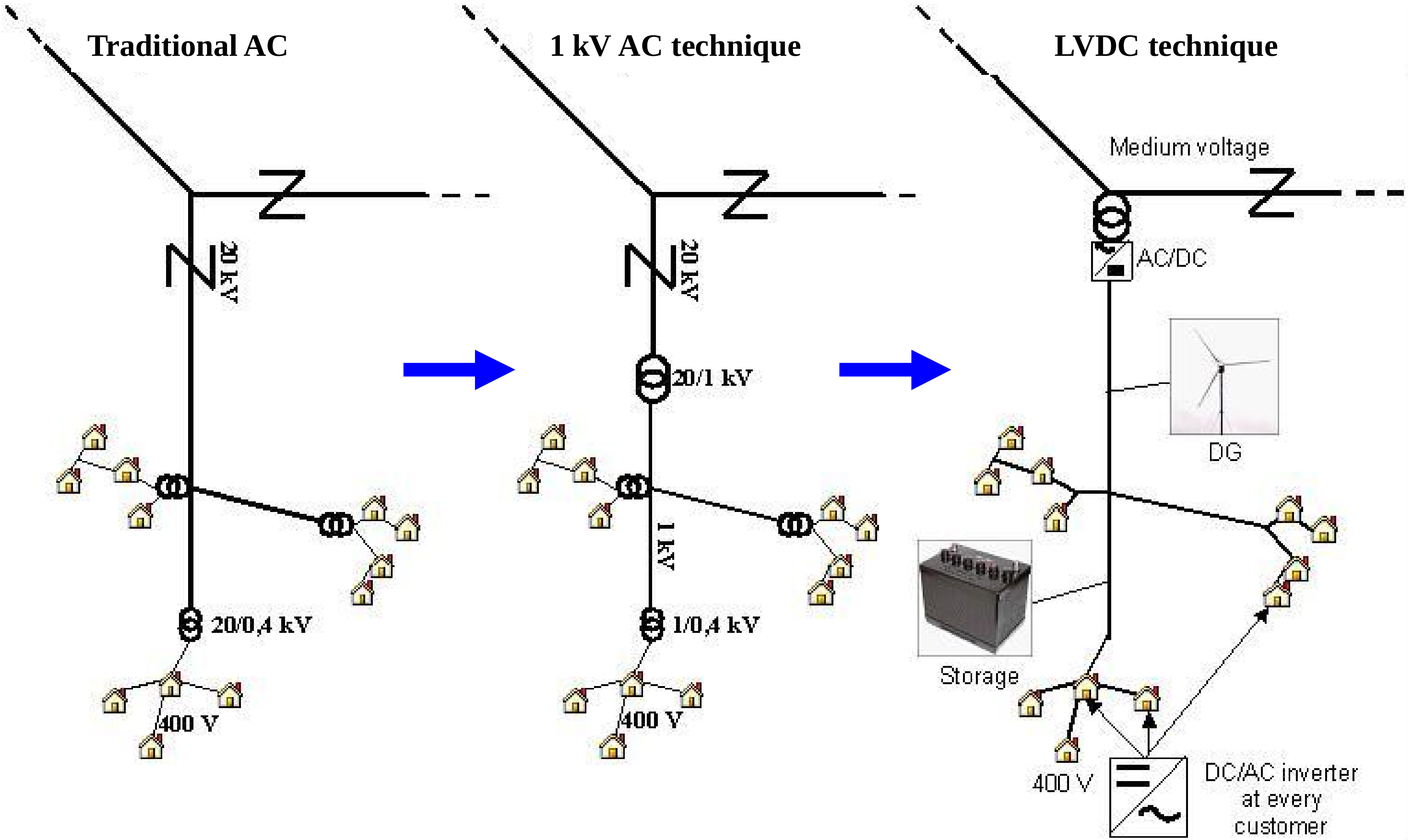


Source: Finnish technology industries association, 2011

Product prices of conventional metals and mechanical industry have increased in average 2 %-units annually. The increase was rapid between years 2003 and 2009, achieving value of 4 %-units/a.

Product prices of electronics industry have decreased in average 5 %-units annually. The decrease have slowed down during past three years to the level of 1 %-unit/a.

Roadmap to LVDC in Finland

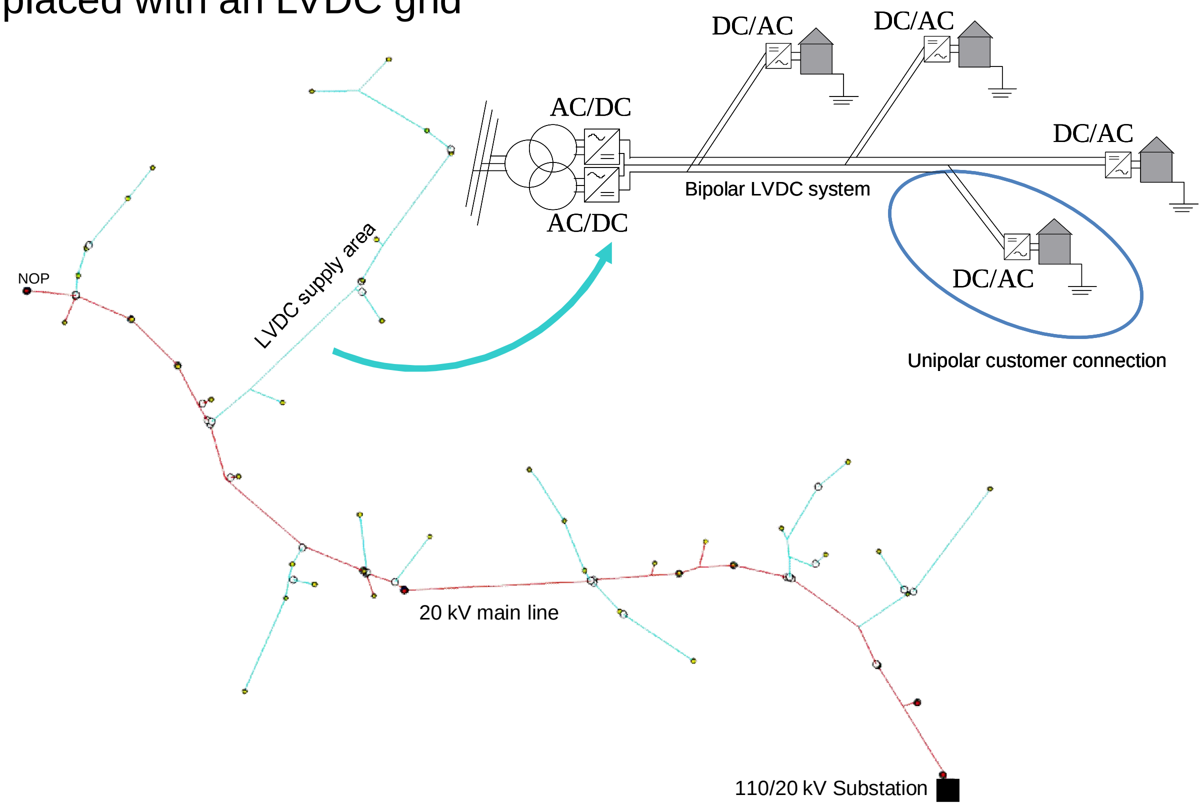


Overall research objectives

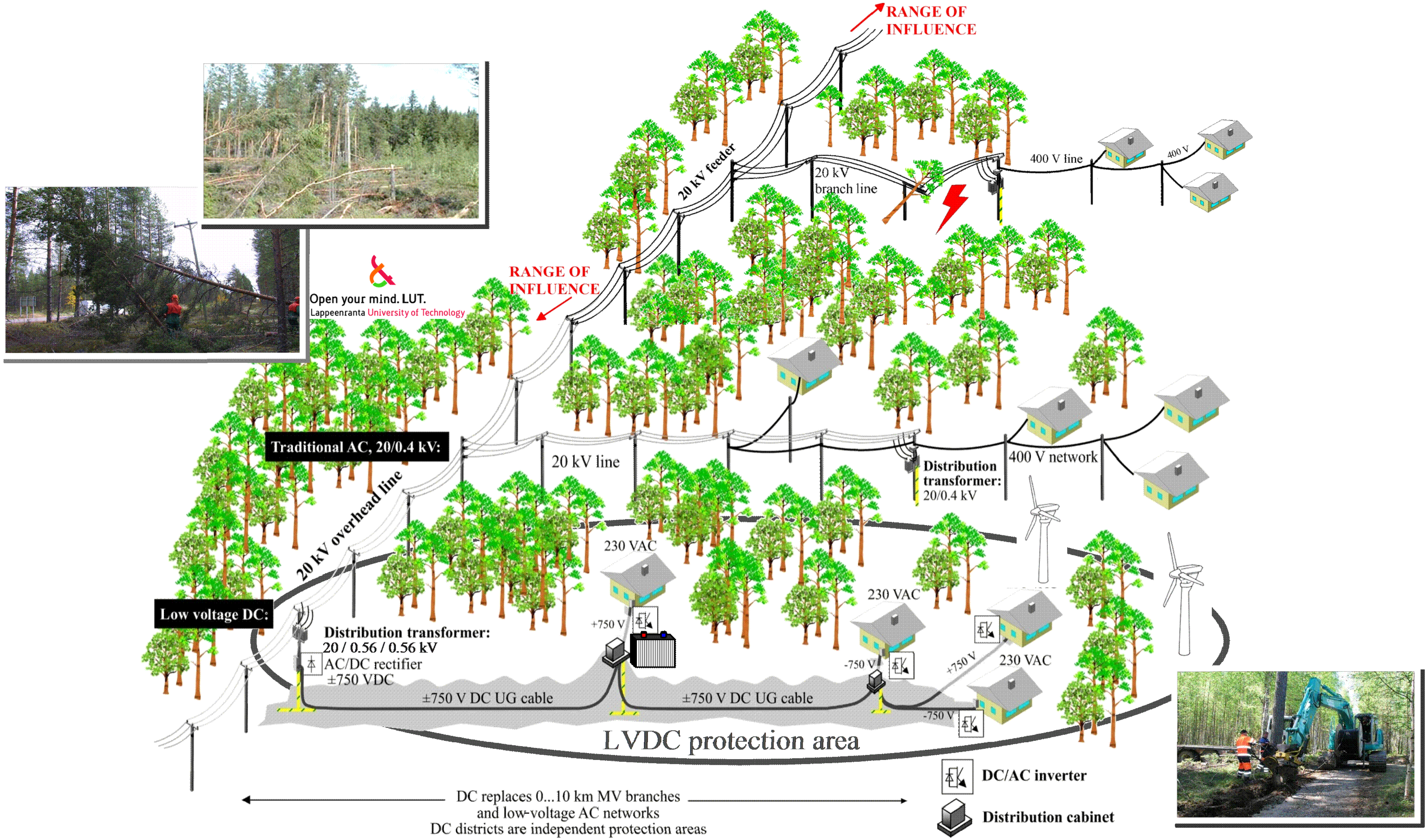
1. **Facilitate improvement of supply quality**
   - Optimising voltage quality for each customer, filtering voltage fluctuations and provide possibility for reducing short interruptions, increasing amount of protection areas in the network
2. **Decrease the life cycle costs of electricity distribution**
   - Decreasing investment costs, optimising maintenance needs, increasing the level of network control and surveillance, supporting conversion towards underground cabled distribution networks
3. **Support increase of small scale generation in distribution networks**
   - Provide simple generation management and standardised connection interface, ease network protection, enable active power flow control, decrease outage times due to network faults
4. **Create opportunities for new business in distribution networks for service providers**
   - VPP-management, network monitoring and local management, data transfer
5. **Support improvement of energy efficiency of the electric energy chain**
   - Decreasing transmission losses, providing possibilities for reducing losses in final use, load control and load peak levelling
6. **Develop and verify technical solutions to achieve profitable system configurations**

Concept of LVDC electricity distribution

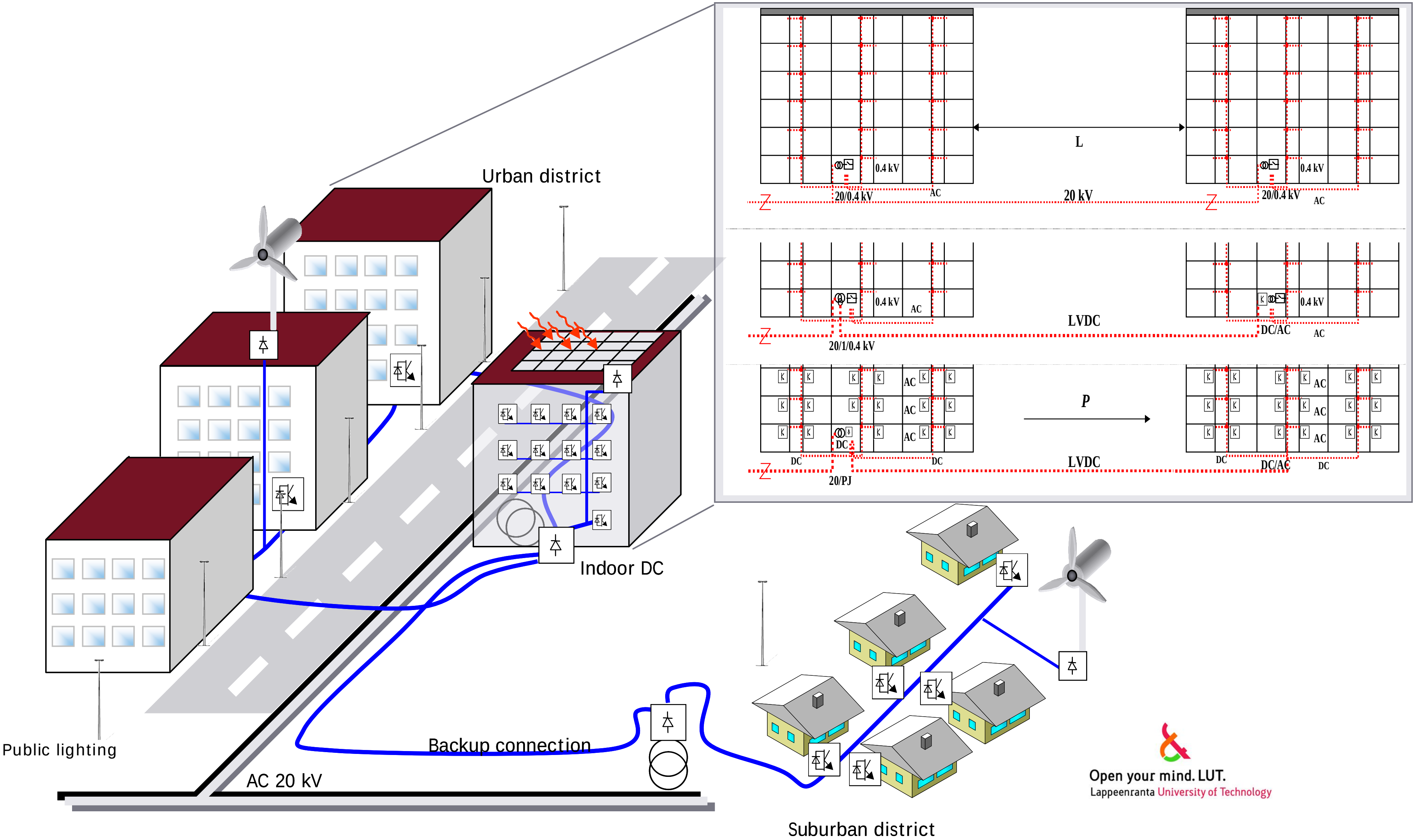
- **According to the EU low voltage directive LVD 2006/95/EC rated voltage of a low voltage DC system is between 75 and 1500 VDC**
- **An LVDC distribution system comprises power electronic converters and DC connection between the converters**
  - The entire low-voltage network is converted to DC
  - Each customer is connected through a DC/AC inverter
  - Lateral medium-voltage AC lines are replaced with an LVDC grid
- **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
  - Low costs of constructing and operating the distribution network



Concept of rural LVDC distribution



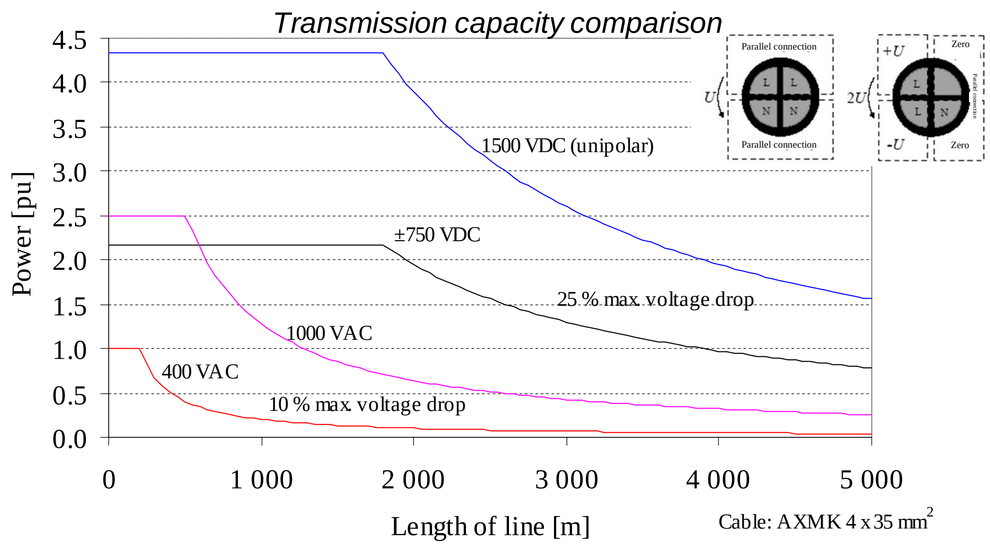
Concept of urban LVDC distribution



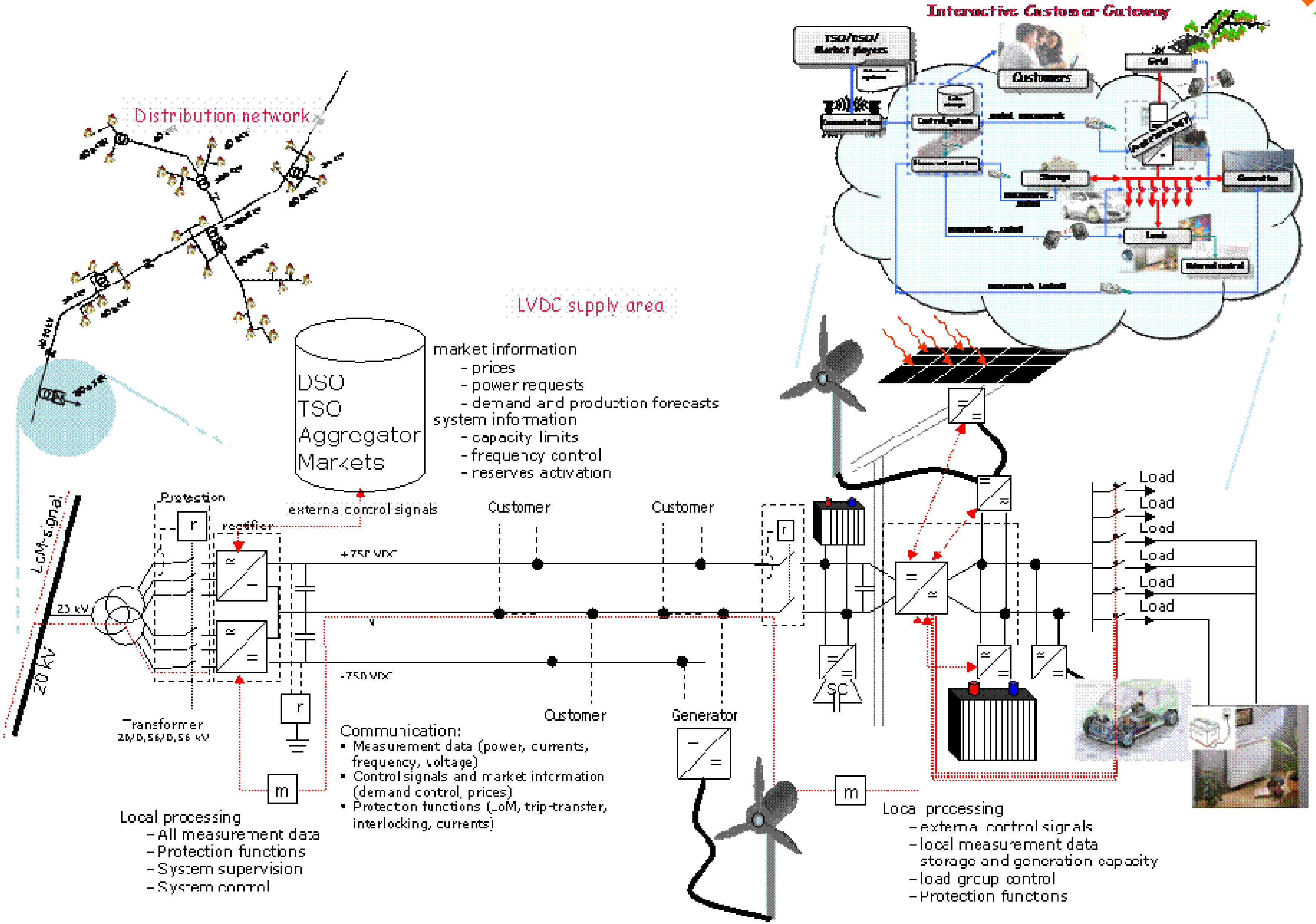
Open your mind. LUT.
Lappeenranta University of Technology

General properties of LVDC system

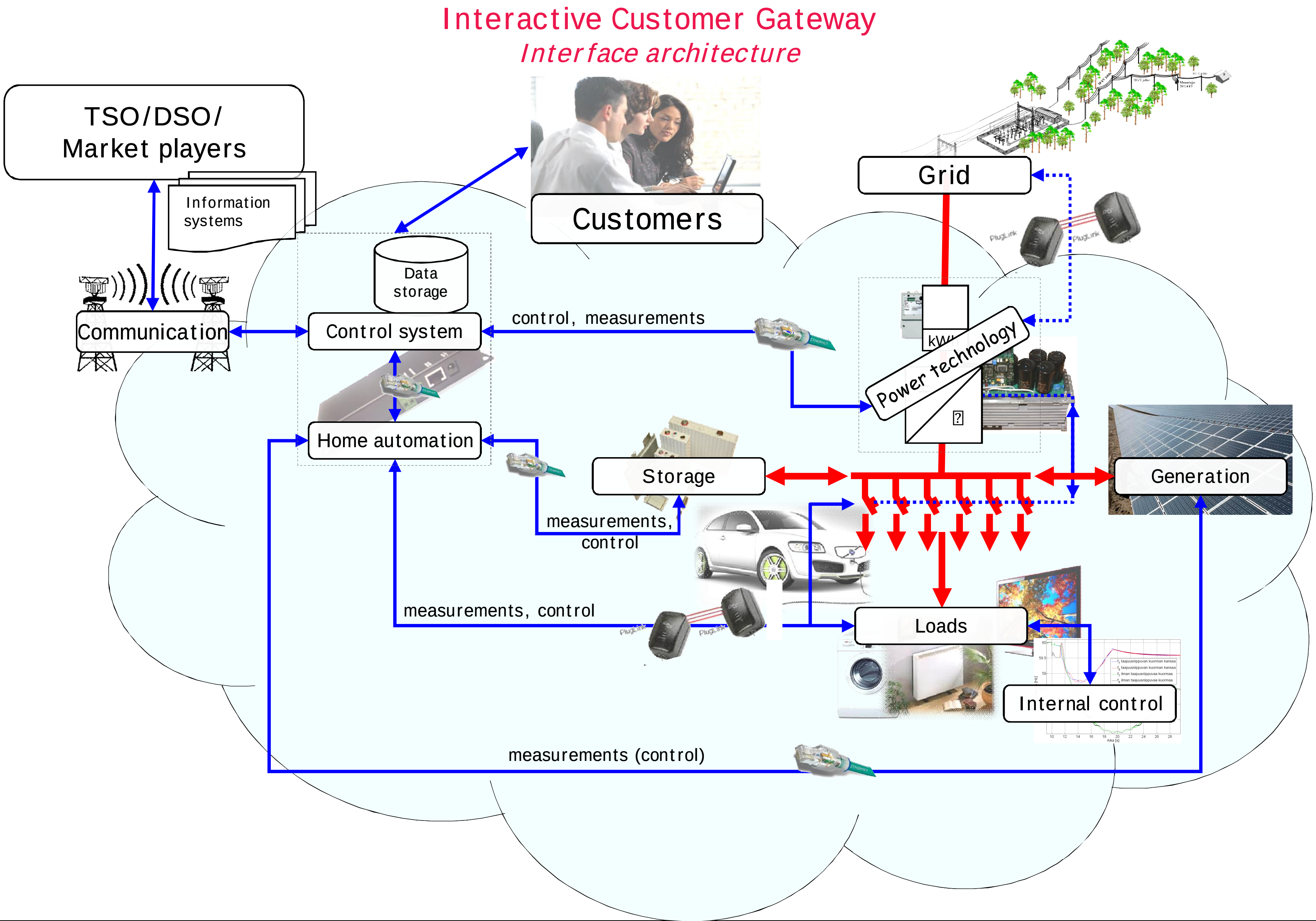
- **Technical properties**
  - Rated DC voltage: 1500 VDC or ±750 VDC (±700 VDC in galvanic continuous system)
  - Max. DC voltage pulsation 10 %
  - Max. DC voltage fluctuation in normal operation -25 % - +10 %
  - Customer AC voltage in normal operation 230 VAC ±0% 50 Hz ±0.1 Hz, THD < 5 % (inside measurement accuracy)
  - Transmission of power <500 kW up to 10 km (case-specific techno-economic solutions)
  - Communication between all converters
- **Basic functionalities**
  - Minimisation of reactive power transmission
  - Constant control of customers' supply voltage
  - Filtration of voltage distortions
  - Self diagnostics of converters
  - Intelligent network protection and fault locating
- **Interactive functionalities**
  - Continuous system supervision
  - Power quality supervision and statistics compilation
  - Grid side power demand control
  - Control of EV charging
  - Market information exchange
- **Optional features**
  - Un-interruptible power supply during outages
  - Power flow control in MV network interface
  - Intentional islanding
  - PFC in MV network interface



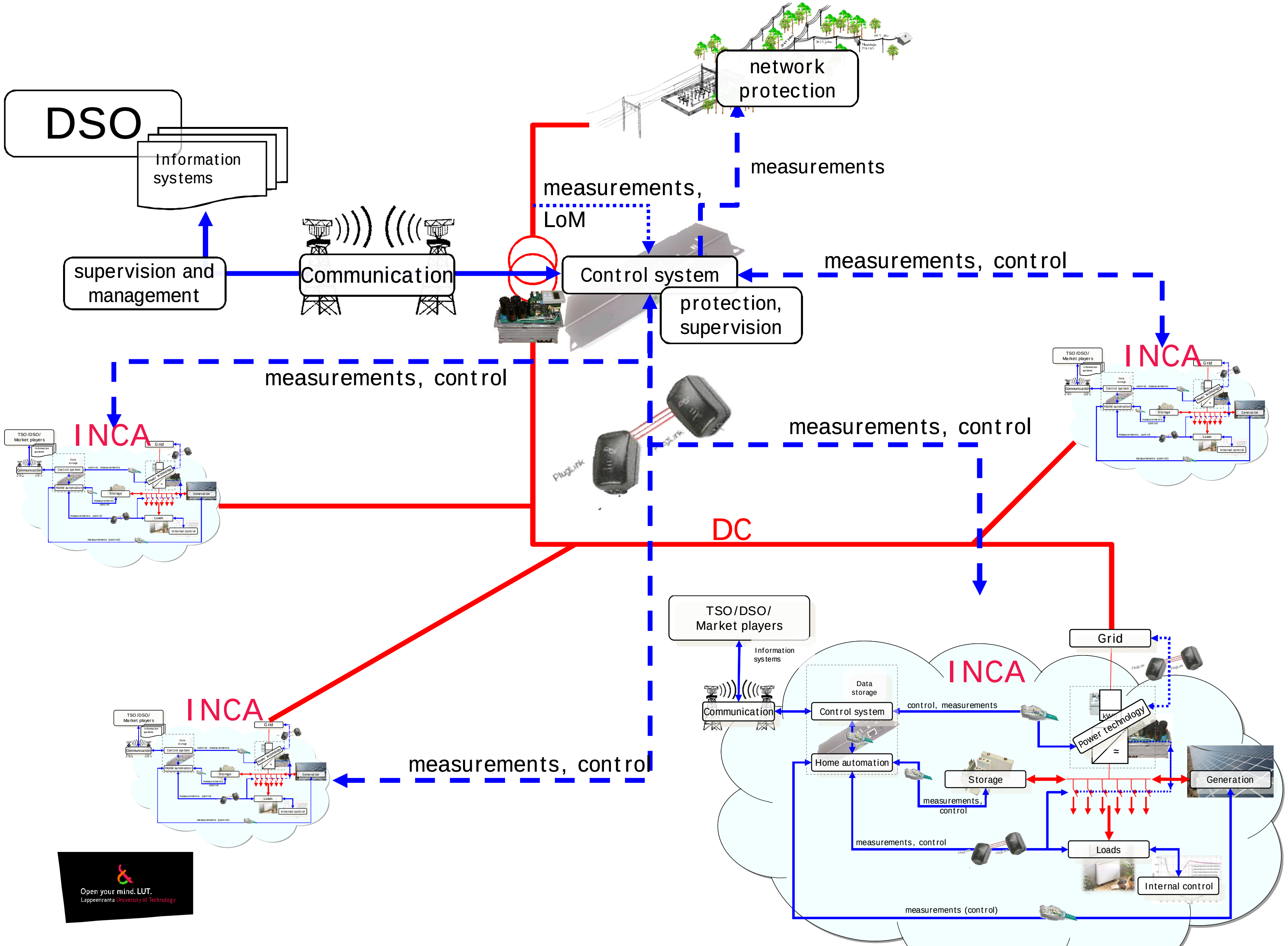
LVDC system layout



Intelligent customer interface in LVDC system



LVDC and network management



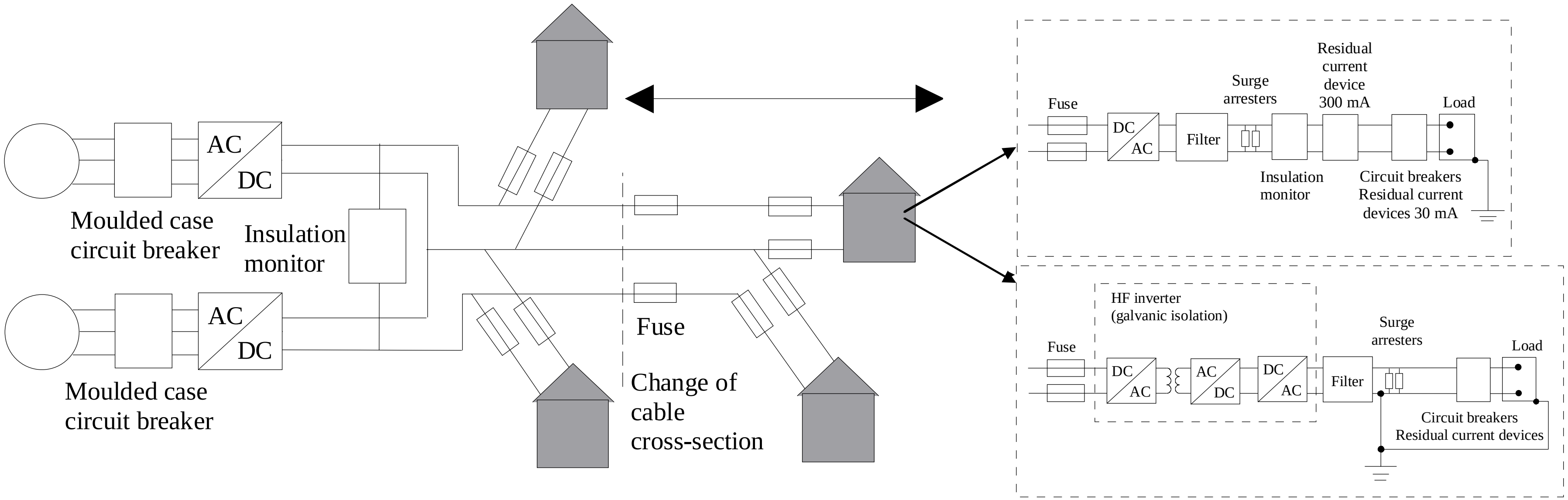
Key research topics

- **System engineering**
  - Conceptual development and functionalities
  - Distribution business impacts
  - Configuration and construction
  - Electric safety and protection
  - Energy efficiency
- **Components**
  - Converters
  - Filters
  - Mechanical structures
  - Measurement technology
  - Reliability
  - Energy efficiency
  - Protection system
  - Cables
- **Implementation**
  - Laboratory research platform
  - Rural environment pilot system
- **Network analyses**
  - Economy
  - Energy efficiency
  - Supply security
  - Power quality
  - Voltage level
  - Topology
  - Protection
- **Tools and methods**
  - System modelling
  - Simulation environments
  - Control engineering
  - Load flow
  - Fault analysis
  - Planning, management
- **ICT**
  - System supervision and control
  - Communication techniques
  - Data security

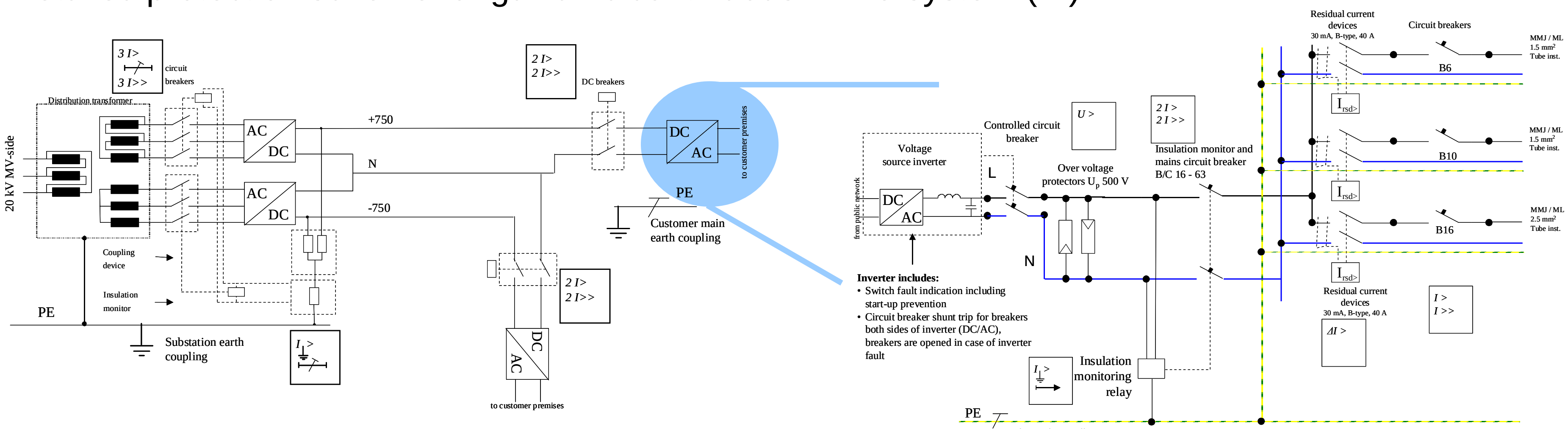
Safety and protection

- **Safety issues are important when implementing new solutions**
  - Contact voltages and currents remain on safe level when the DC network is operated isolated from ground (IT)
  - Grounding scheme of public DC and customer's AC networks have to equal if galvanic isolation is not provided in their connection point
  - Customer equipotential bonding and grounding impedances are important in all grounding schemes
- **Safety, protection and possible grid events have to be considered in converter design and control**
  - The most simple converter structures provide inexpensive, reliable and energy efficient voltage conversion but are challenging from safety perspective due to galvanic connection between DC and AC networks
  - Galvanic isolation provides "easy" way from safety viewpoint but is challenging from economy, energy efficiency and converter topology viewpoints
  - Common mode disturbances due to inverter modulation cause excess voltage stress for the components in customer AC networks
- **ICT solutions in the LVDC provide possibility of intelligent protection system**
  - Integration of protection functions into converter control algorithms give freedoms for power switch current capacity dimensioning
  - Remote tripping and interlocking can be used to ensure selectivity
  - Teleprotection algorithms such as differential protection provide interesting alternative for solving the protection challenges of microgrids and island operation

Basic protection system layouts



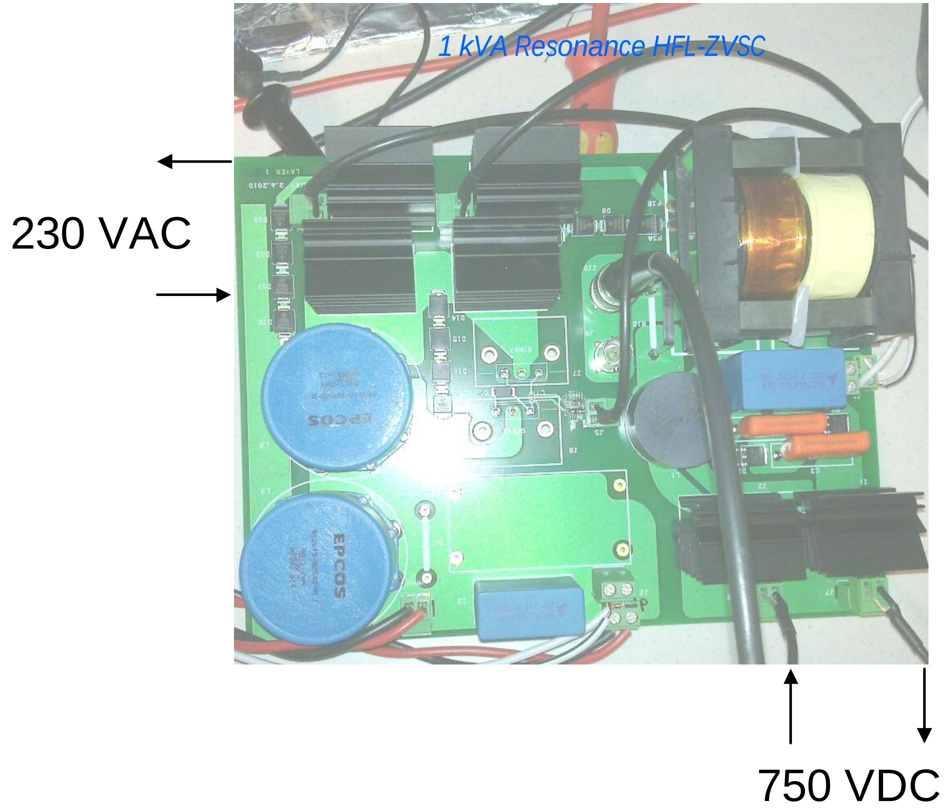
Detailed protection scheme for galvanic continuous LVDC system (IT)



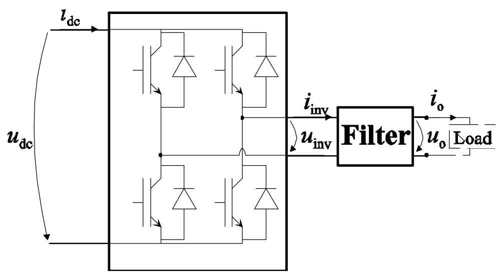
DC network *Customer's AC network*

Converter technology

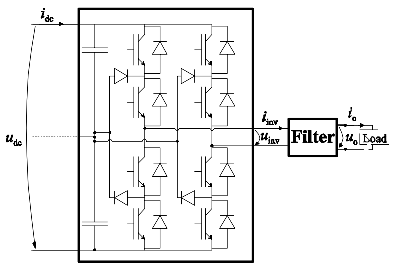
- Converters with (HFL, High-frequency-link converter) and without galvanic isolation
- Two and three level solutions
- Filter topologies and core materials
- Losses reduction
- Size and mass reduction
- Lifetime extension
- Reliability improvement
- Design guidelines and methods



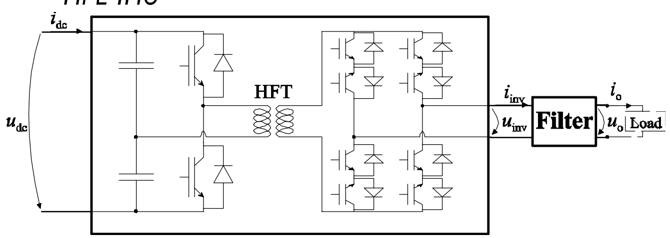
Two-level full-bridge



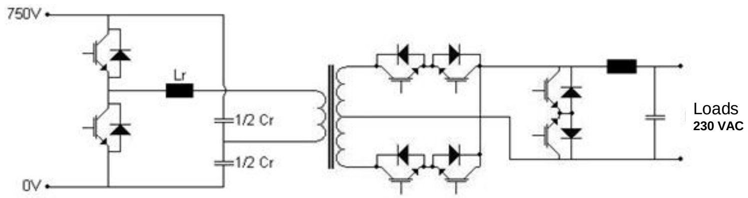
Three-level full-bridge



HFL-IHC



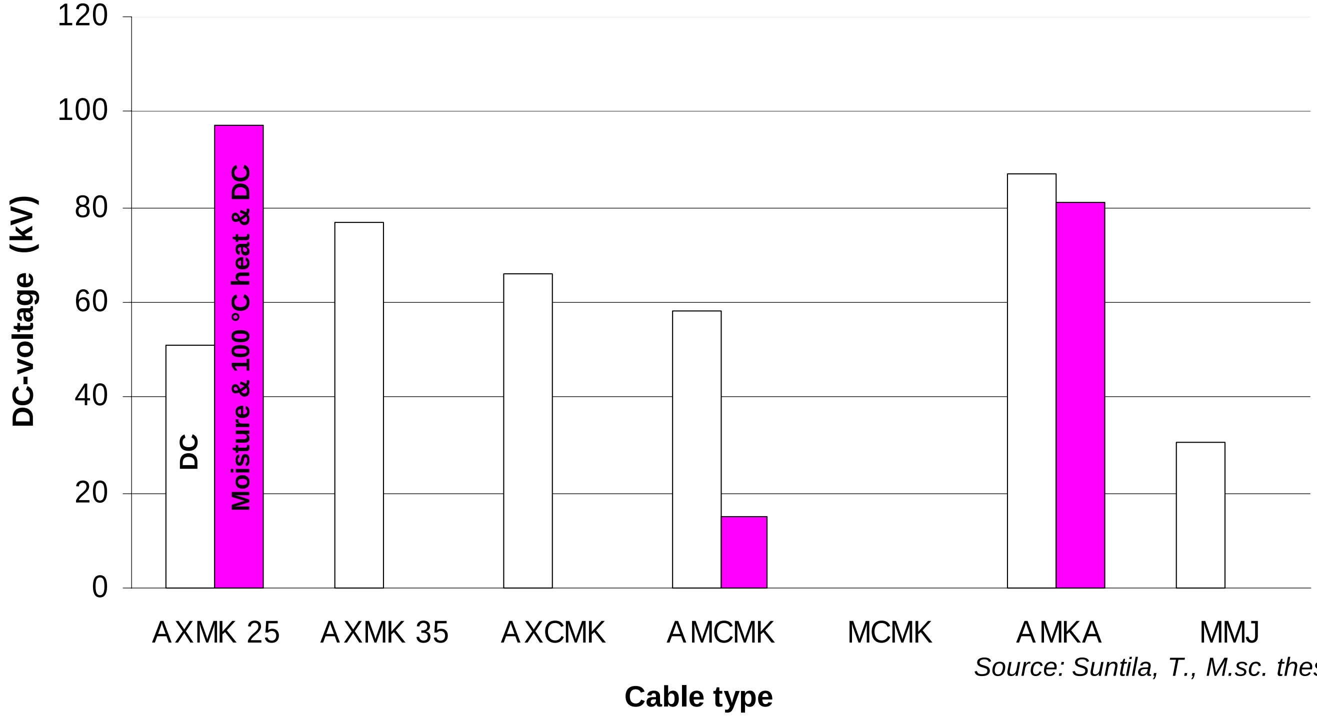
Resonance HFL-ZVSC



Sources: *Peltoniemi, P., Dissertation, LUT 2010*
Kampe, M., Takala, J., Juntunen, R., Karttunen, J., B.Sc. thesis, LUT 2009

Low voltage DC cables

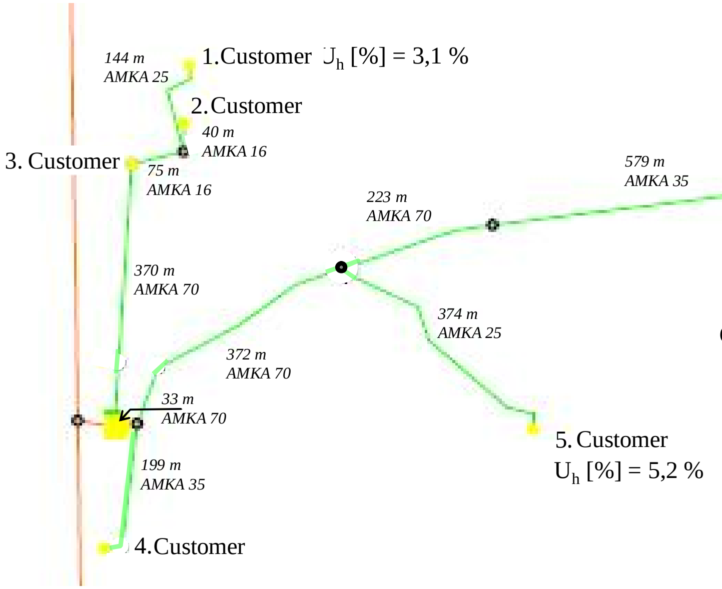
- **Conventional low voltage AC power cables suitable for LVDC distribution!**
  - Insulation material should be non-polar dielectric, because of high frequency signal of PLC -> XLPE insulation
  - XLPE insulation withstand DC voltage stress in all circumstances better than than PVC insulation
  - Concentric neutral conductor with groundings provides shield against high frequency interferences



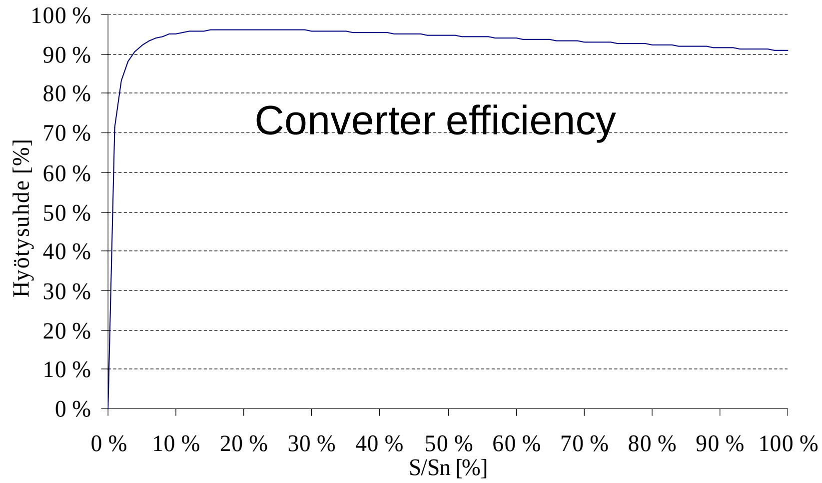
Source: Suntila, T., M.sc. thesis, TUT 2009

DC voltage withstand capacity of conventional low voltage cables

Energy Efficiency



Cust.	Energy/a [kWh]	curve	Peak power kW	Peak power kVAr
1.	17720	1	5,2	1,5
2.	10580	1	3,1	0,9
3.	19830	2	14,7	4,2
4.	19815	8	5,3	1,6
5.	17680	6	7,2	2,0
6.	1290	6	0,5	0,1
7.	35700	6	13,8	3,8

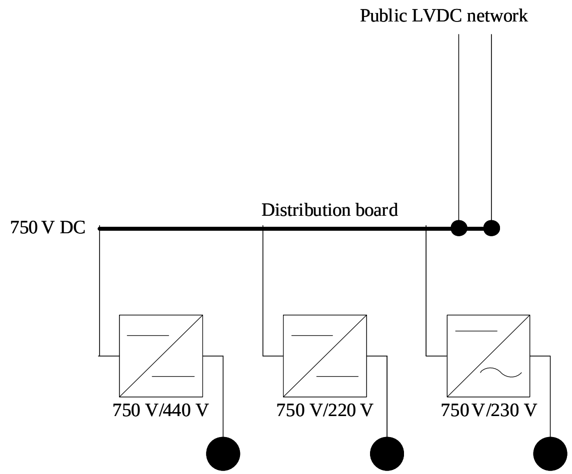


LV system losses [kWh]	400 VAC	LVDC	Difference
Transformers	2917	3157	8 %
Lines	4577	1061	-77 %
Rectifiers	-	1903	100 %
Inverters	-	7092	100 %
Total	7494	13214	76 %

Total energy losses can be reduced 30–40 % by increasing efficiency of customer-end converters

Energy Efficiency

- **Annual energy efficiency overcomes rated power efficiency as main indicator of total energy efficiency performance of converters**
- **Main source of converter losses are produced in filters and power switches**
  - Filter structures and modulation control need to be optimised with respect to the life cycle total costs of a converter
- **Customer inverter structures have high impact on**
  - Energy efficiency of DC/AC and AC/DC conversions
  - reliability and maintainability of the system
  - Safety and security of system
  - Price of inverter

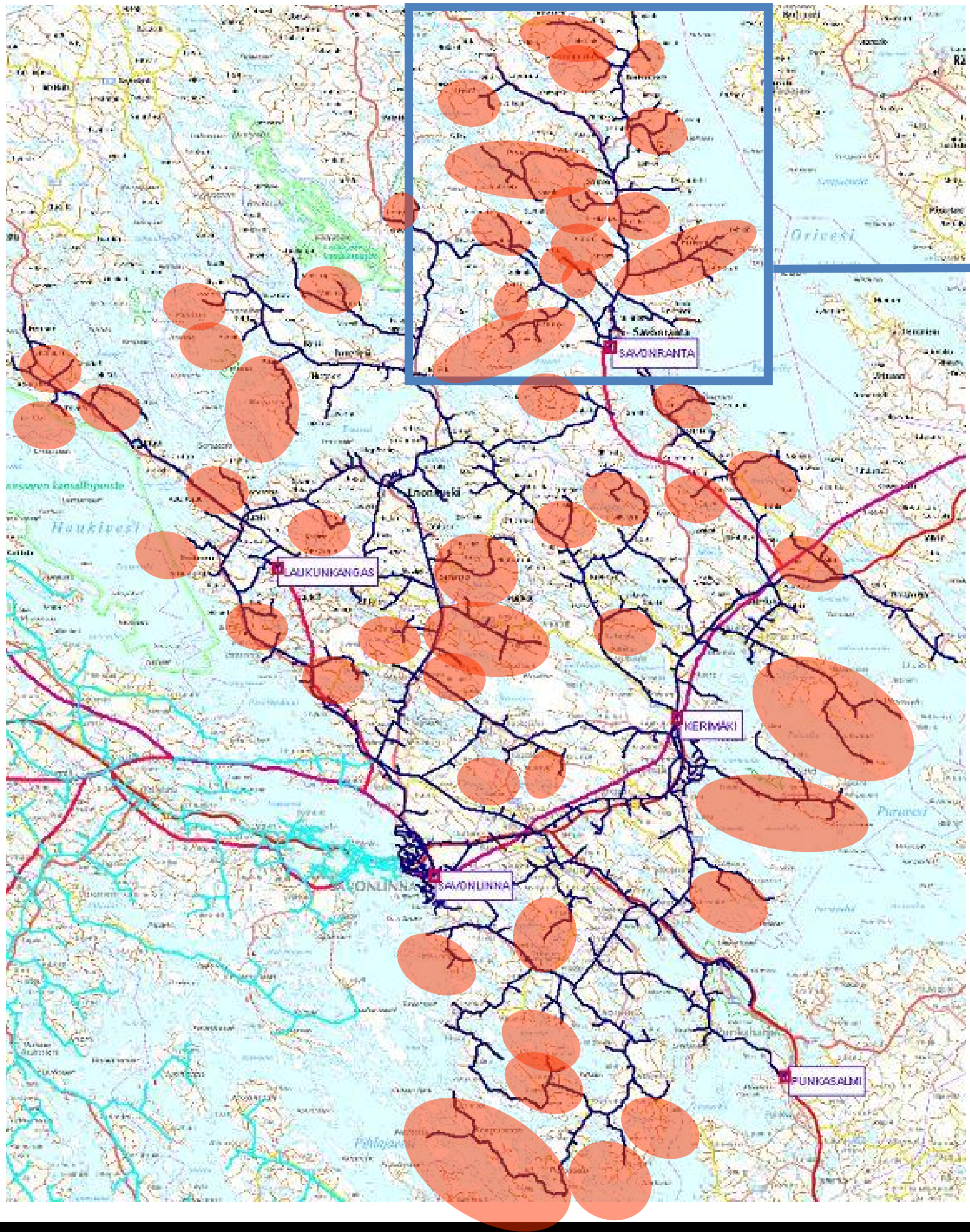


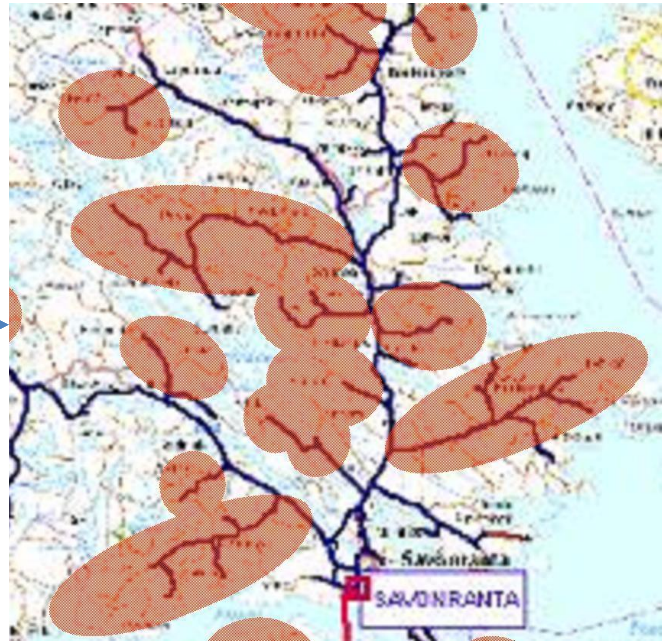
- **Modular parallel converter structures have impact on energy efficiency and costs but also to reliability and total costs**
  - DC distribution in customer premises and dispersion of inverters?

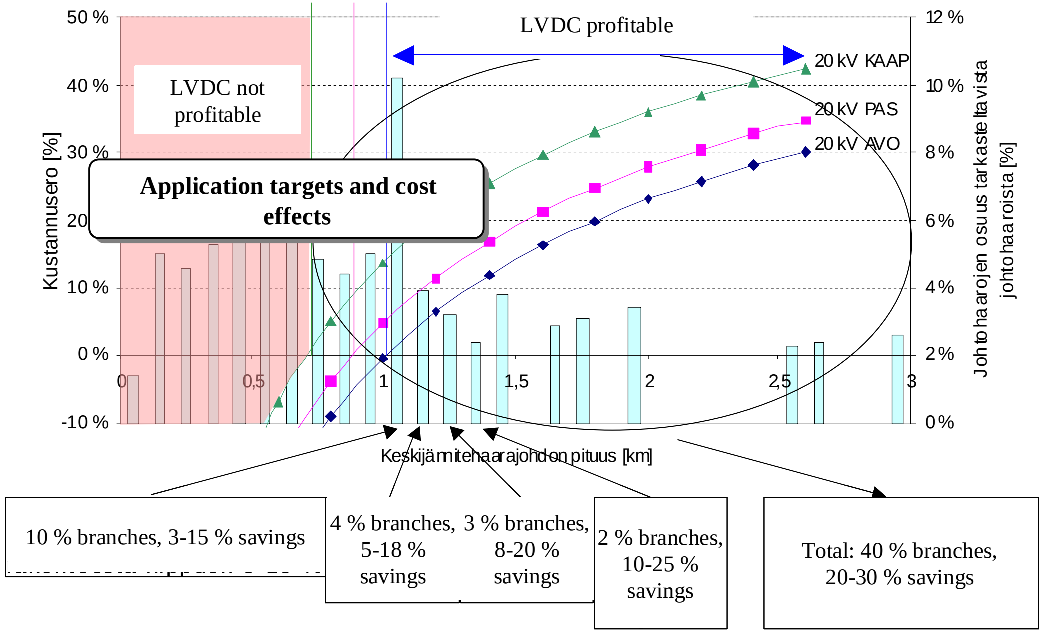
Network planning

- **Strategic planning**
  - How to evaluate the strategic role and application potential of LVDC distribution?
  - What is the impact of the LVDC on other network structures?
- **Long term detailed planning**
  - Where the LVDC system can be used, how to pinpoint the suitable application targets?
  - How the application of the LVDC system affect on MV network nearby the application target
- **Detailed target planning**
  - What are the optimal LVDC network constructions in particular application target?
- **LVDC system planning is a part of dynamic planning process of MV networks**
- **Where is the line between network planning and component design?**
  - i.e. DC capacitor or reactor dimensioning can be included in both

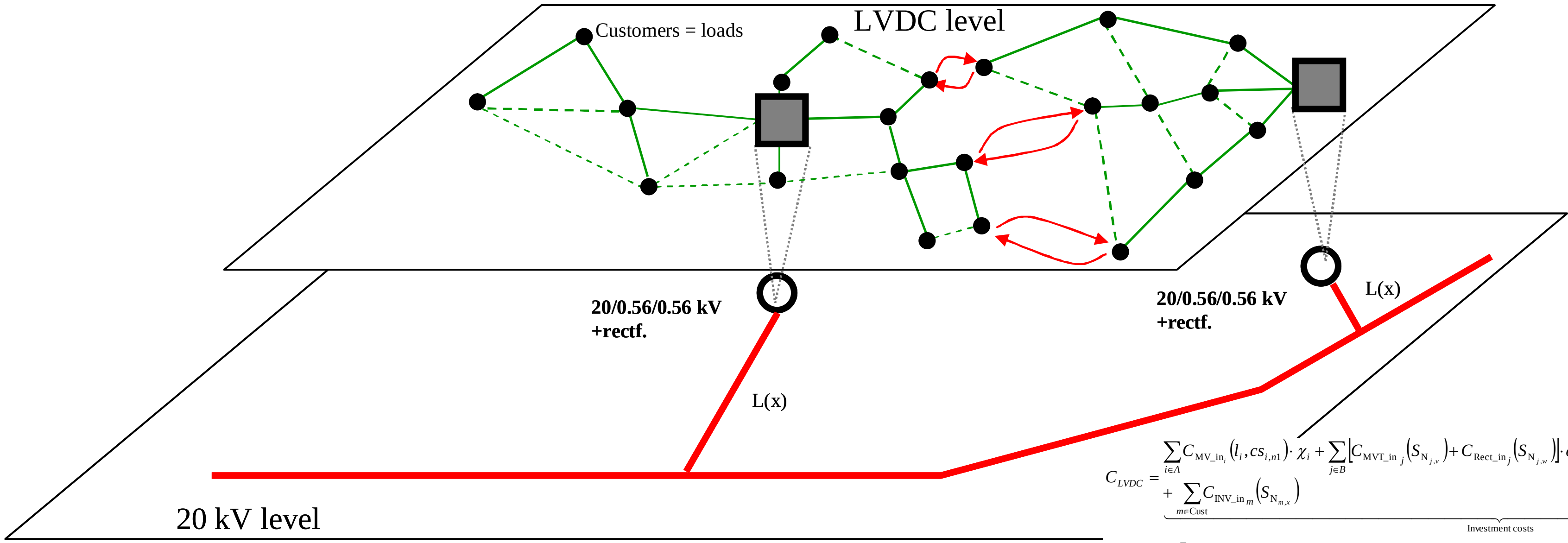
Strategic planning
– Application potential analysis

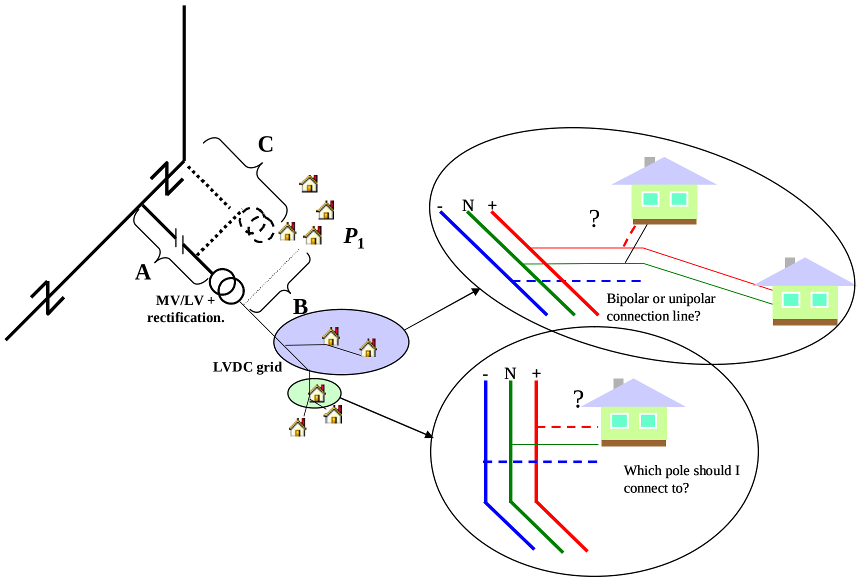






Detailed planning
– Supply area optimisation





$$C_{LVDC}=\underbrace{\begin{matrix}\sum_{i\in A}C_{\mathrm{MV\_in}_i}\left(l_i,cs_{i,n1}\right)\cdot\chi_i+\sum_{j\in B}\left[C_{\mathrm{MVT\_in}_j}\left(S_{\mathrm{N}_{j,v}}\right)+C_{\mathrm{Rect\_in}_j}\left(S_{\mathrm{N}_{j,w}}\right)\right]\cdot\alpha(\chi_i,\gamma_k)_j+\sum_{k\in D}C_{\mathrm{LV\_in}_k}\left(l_k,cs_{k,n2},pl_k\right)\cdot\gamma_k\\+\sum_{m\in \mathrm{Cust}}C_{\mathrm{INV\_in}_m}\left(S_{\mathrm{N}_{m,x}}\right)\end{matrix}}_{\text{Investment costs}}\ldots$$

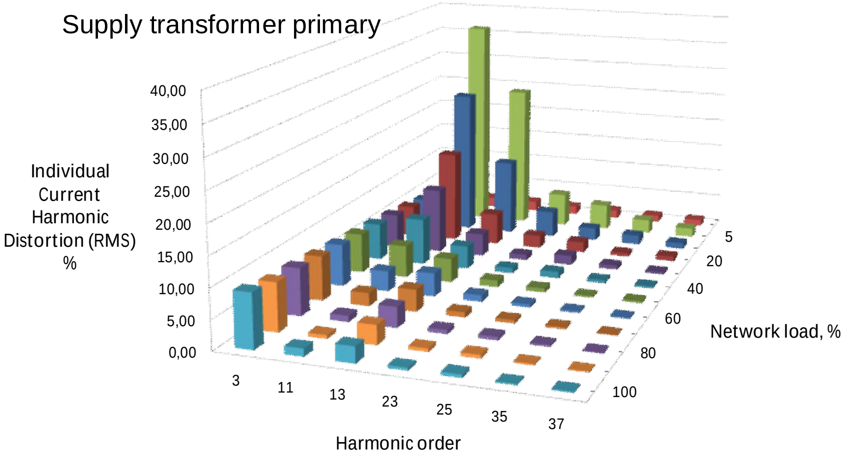
$$\underbrace{\ldots+h_{\mathrm{L}}\cdot\int_0^{8760}\left[\begin{matrix}\left[\begin{matrix}\sum_{i\in \mathrm{A}}C_{\mathrm{MV\_LL}_i}\left(l_i,\left(\frac{S_{\mathrm{MV}}(t)}{U(t)}\right)_i^2,cs_{i,n1}\right)\cdot\chi_i\\+\sum_{j\in \mathrm{B}}\left(C_{\mathrm{MVT\_LL}_j}\left(\left(\frac{S_{\mathrm{MVT}}(t)}{S_{\mathrm{N}_v}}\right)_j^2,P_{\mathrm{LL\_N}_{j,v}},\mathrm{THD}\right)+C_{\mathrm{Rect\_LL}_j}\left(\eta_{j,w},S(t)_{j,w}\right)\right)\cdot\alpha(\chi_i,\gamma_k)_j\\+\sum_{k\in \mathrm{D}}C_{\mathrm{LV\_LL}_k}\left(l_k,\left(\frac{S_{\mathrm{MV}}(t)_{\mathrm{ng}}}{U(t)}\right)_k^2,\left(\frac{S_{\mathrm{MV}}(t)_{\mathrm{pos}}}{U(t)}\right)_k^2,cs_{k,n2},pl_k\right)\cdot\gamma_k+\sum_{m\in \mathrm{Cust}}C_{\mathrm{INV\_LL}_m}\left(\eta_{m,x},S(t)_{m,x}\right)\end{matrix}\right]\cdot\kappa_{\mathrm{LL}}\\\ldots+\left[\sum_{j\in \mathrm{B}}\left(C_{\mathrm{MVT\_NL}_j}\left(\left(\frac{U(t)}{U_N(t)_j}\right),P_{\mathrm{NL\_N}_{j,v}}\right)+C_{\mathrm{Rect\_NL}_j}\left(P_{\mathrm{NL\_N}_{j,w}}\right)\right)\cdot\alpha_j+\sum_{m\in \mathrm{Cust}}C_{\mathrm{INV\_NL}_m}\left(P_{\mathrm{NL\_N}_{m,x}}\right)\right]\cdot\kappa_{\mathrm{NL}}\end{matrix}\right]dt\ldots}_{\text{Costs of losses}}$$

$$\underbrace{\begin{matrix}\ldots+\sum_{i\in \mathrm{A}}\left[\begin{matrix}\lambda_{\mathrm{PF}_i}\cdot\left(\sum_{nc\in \mathrm{Z}}\frac{W_{\mathrm{Z}_{\mathrm{nc}}}\cdot b_{nc}\cdot t_{rep}}{8760}+\sum_{nc\in \mathrm{RZ}}\frac{W_{\mathrm{RZ}_{\mathrm{nc}}}\cdot b_{nc}\cdot t_{mc}}{8760}+\sum_{nc\in \mathrm{feeder}}\frac{W_{\mathrm{nc}}}{8760}\cdot\left(a_{nc}+b_{nc}\cdot t_{rc}\right)\right)\\+\lambda_{\mathrm{HSR}_i}\cdot\sum_{nc\in \mathrm{feeder}}\frac{W_{\mathrm{nc}}\cdot a_{\mathrm{HSR}\,nc}}{8760}+\lambda_{\mathrm{DR}_{\mathrm{nc}}}\cdot\sum_{nc\in \mathrm{feeder}}\frac{W_{\mathrm{nc}}\cdot a_{\mathrm{DR}\,nc}}{8760}\end{matrix}\right]\cdot l_i\cdot\chi_i\ldots\\\ldots+\sum_{j\in \mathrm{B}}\sum_{nc\in \mathrm{TD}}\left(\lambda_{\mathrm{MVT}\,j}+\lambda_{\mathrm{Rect}\,j}\right)\cdot\frac{W_{nc}}{8760}\cdot\left(a_{nc}+b_{nc}\cdot t_{\mathrm{rep2}}\right)\cdot\alpha(\chi_i,\gamma_k)_j+\sum_{k\in \mathrm{D}}\sum_{nc\in TD}\lambda_{\mathrm{PF}k}\cdot\frac{W_{\mathrm{nc}}}{8760}\cdot\left(a_{nc}+b_{nc}\cdot t_{\mathrm{rep3}}\right)\cdot\gamma_k\ldots\\\ldots+\sum_{m\in \mathrm{Cust}}\lambda_{\mathrm{INV}\,m}\cdot\frac{W_{\mathrm{m}}}{8760}\cdot\left(a_m+b_m\cdot t_{\mathrm{rep4}}\right)\ \ldots\end{matrix}}_{\text{Statistical outage costs}}$$

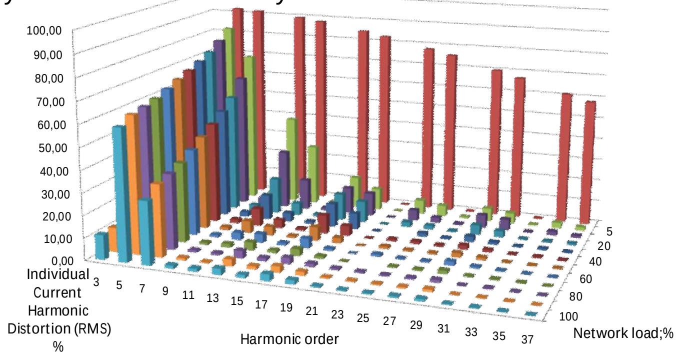
$$\ldots+\underbrace{\sum_{i\in \mathrm{A}}C_{\mathrm{MV\_md}_i}\cdot\chi_i+\sum_{j\in \mathrm{D}}C_{\mathrm{LV\_md}\,j}\cdot\beta_i}_{\text{Costs of major disturbances}}$$

Detailed planning
– Harmonics and power losses

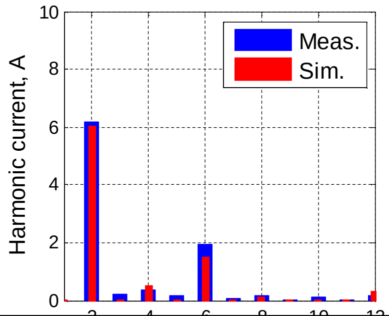
Supply transformer primary



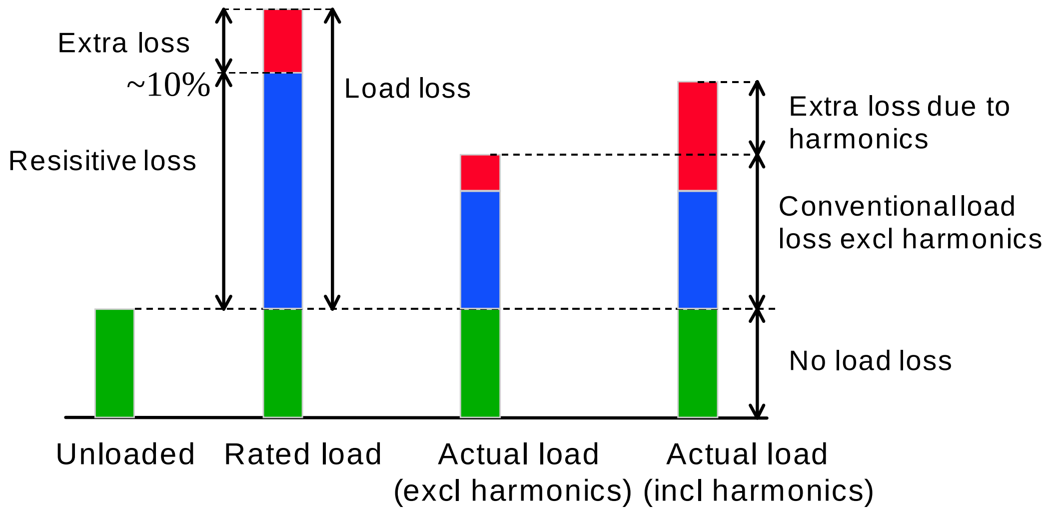
Supply transformer secondary



DC network C_{rec}=1000µF and C_{inv}=250µF.



Supply transformer losses



Source: Hulshorst, W.T.J., et Al., Kema 2009

$$P_{LL\_tot} = P_{LL1} \times \left(\frac{I_L}{I_1}\right)^2 + P_{WE1} \times \left(\sum_1^n \left(\frac{I_h}{I_1}\right)^2 h^2\right) + \left(P_{CE1} + P_{SE1}\right) \times \left(\sum_1^n \left(\frac{I_h}{I_1}\right)^2 h^{0,8}\right)$$

Conventional load loss — Eddy current loss in windings — Stray losses

- I_L = RMS value of the sinusoidal current including all harmonics
- I_1 = RMS value of the fundamental current, at rated load
- I_h = RMS value of the harmonic current of order h
- P_{LL1} = copper losses of the fundamental freqency at rated load
- P_{WE1} = winding eddy loss at rated frequency and load
- P_{CE1} = connectors eddy loss at rated frequency and load
- P_{SE1} = stary loss in structures at rated frequency and load

$$I_L = \sqrt{\sum_1^n I_h^2}$$

$$I_h = \frac{I_{1L}}{\left(h - \frac{5}{h}\right)^{1,2}}$$

Source: IEC 61378-1

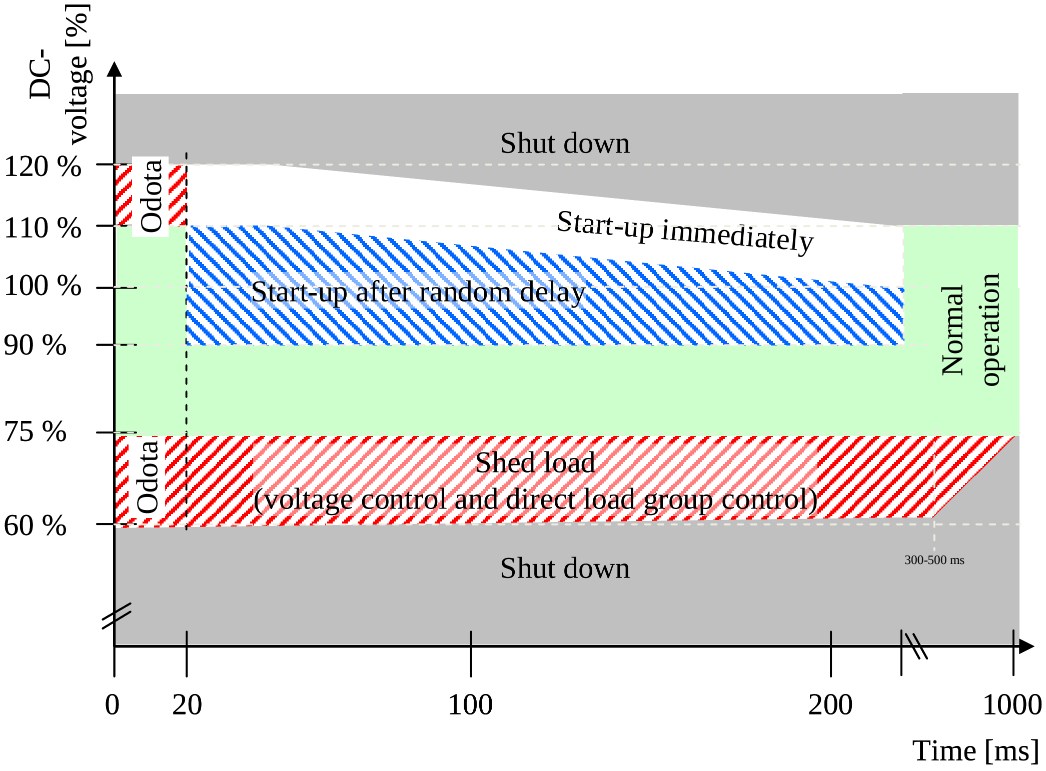
Detailed planning
– Harmonics and power losses

Name	CASE 1	CASE 2	CASE 3	CASE 4
Capacitors	Rated	Oversized	Undersized	Undersized
C_{rec}	1.2mF	2.4mF	600µF	1.2mF
C_{inv}	720µF	1.4mF	720µF	360µF
Power losses in kW				
$P^{h}_{dc\ network}$	0.485	0.11	1.51	0.54
$P^{h}_{transformer}$	0.074	0.072	0.067	0.081
$P^{dc}_{dc\ network}$	1.31	1.31	1.36	1.31
$P^{50Hz}_{transformer}$	0.31	0.325	0.37	0.355
Total	2.179	1.81	3.3	2.28

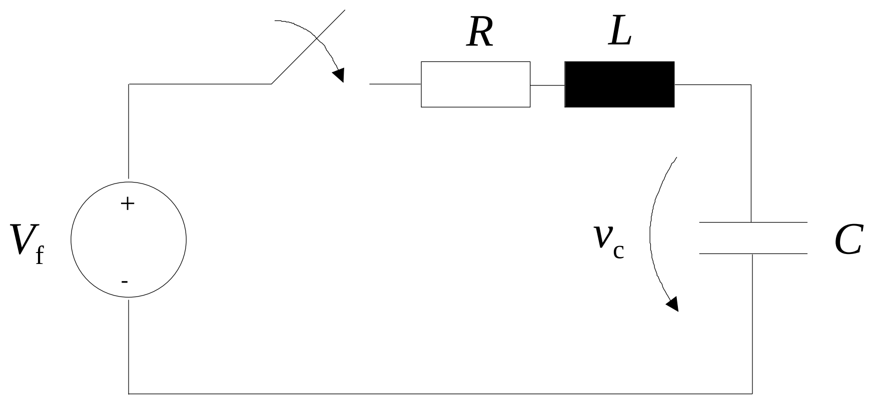
- **Distortion losses in DC network form ~20-30 % of the total line losses when capacitors are dimensioned only on technical basis (voltage ripple + stability)**
- **Economical dimensioning can lead to larger capacitor sizes**

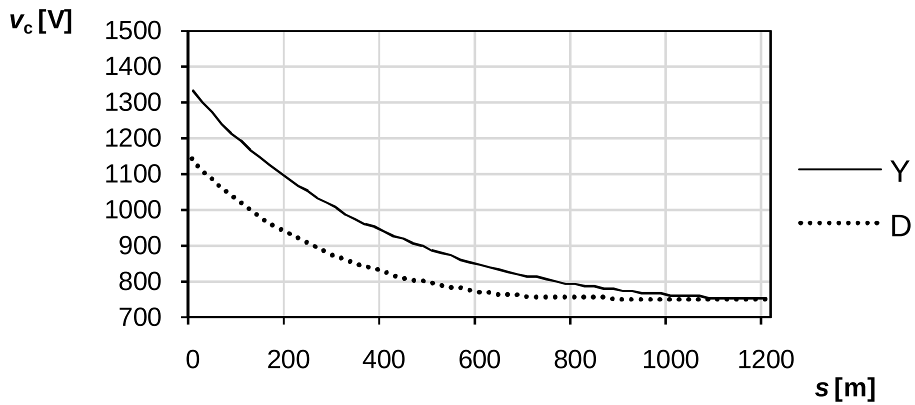
$$\left(\Delta P^{\mathrm{h}}_{\mathrm{dc\ network}} + \Delta P^{\mathrm{h}}_{\mathrm{transformer}}\right) \cdot price_{\mathrm{losses}} > \Delta Cost_{\mathrm{capacitor}}$$

Planning of operation and start-up



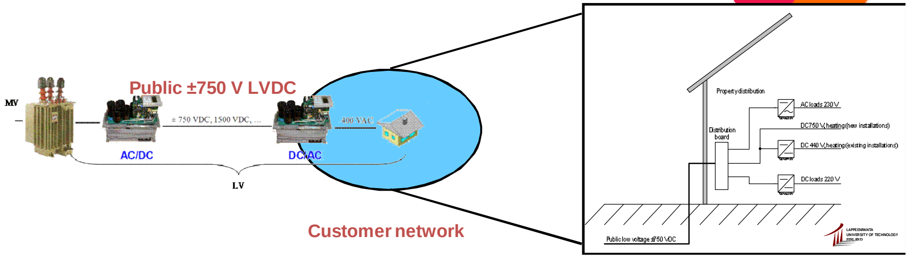
Example of converter operation based on DC voltage



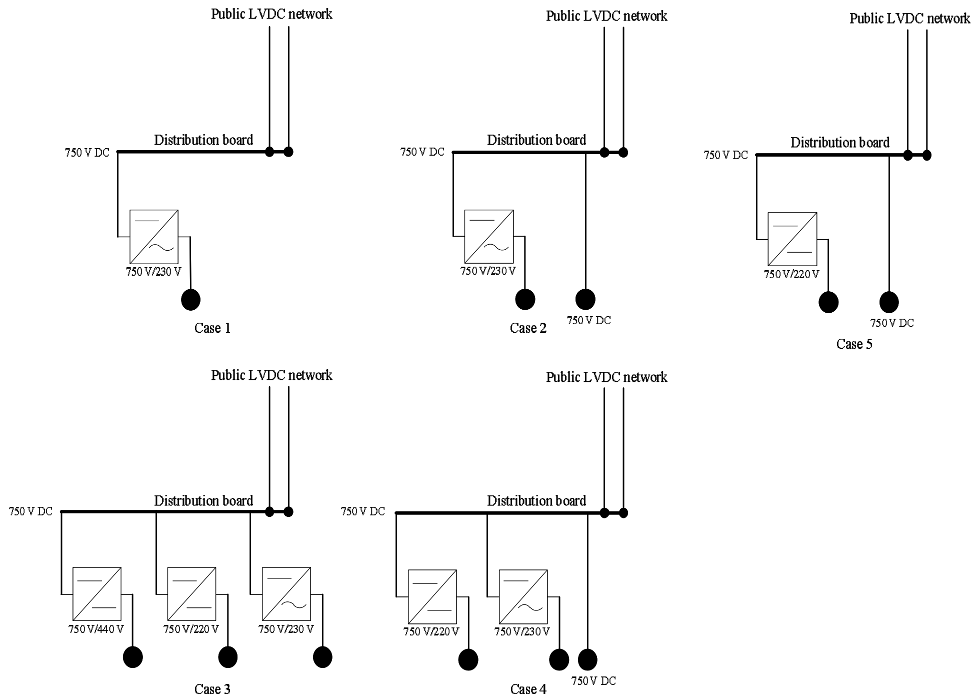


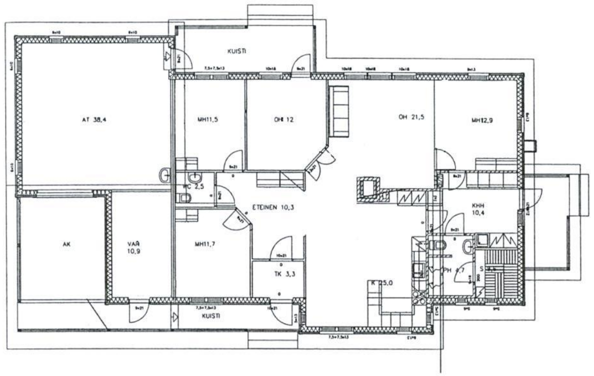
Capacitor voltage after start-up as a function of cable length with star and delta-connected secondary

LVDC in residential buildings



- **Majority of low-voltage electronic devices use internally DC voltages**
  - Internal SMPS converters
  - Resistive heating and lights work both with DC and AC, and some even better with DC
- **DC voltage level can be higher than the level used in LV AC circuits at present**
  - Higher transmission capacity
  - Internal voltages of electronic devices are not suitable for distribution

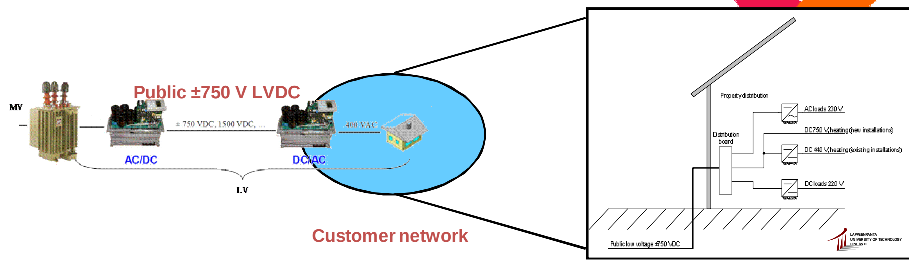


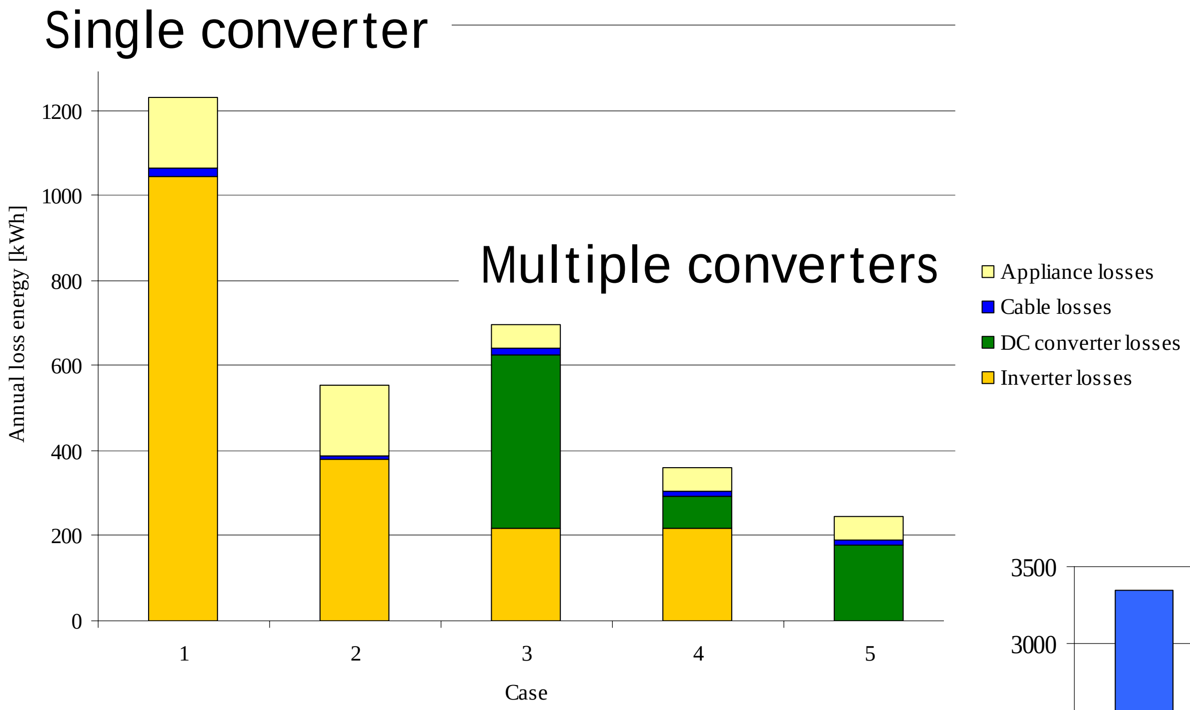


- **Case 1 has only one voltage level, 230 VAC produced with a centralised inverter**
- **Case 2 has 750 VDC for heating and 230 VAC for other devices**
- **Case 3 has multiple voltage levels**
- **Case 4 is similar to Case 3, but there is 750 VDC instead of 440 VDC**
- **Case 5 provides two voltage levels, 750 VDC and 220 VDC**

Source: Paajanen, P., M.Sc. thesis, LUT 2009

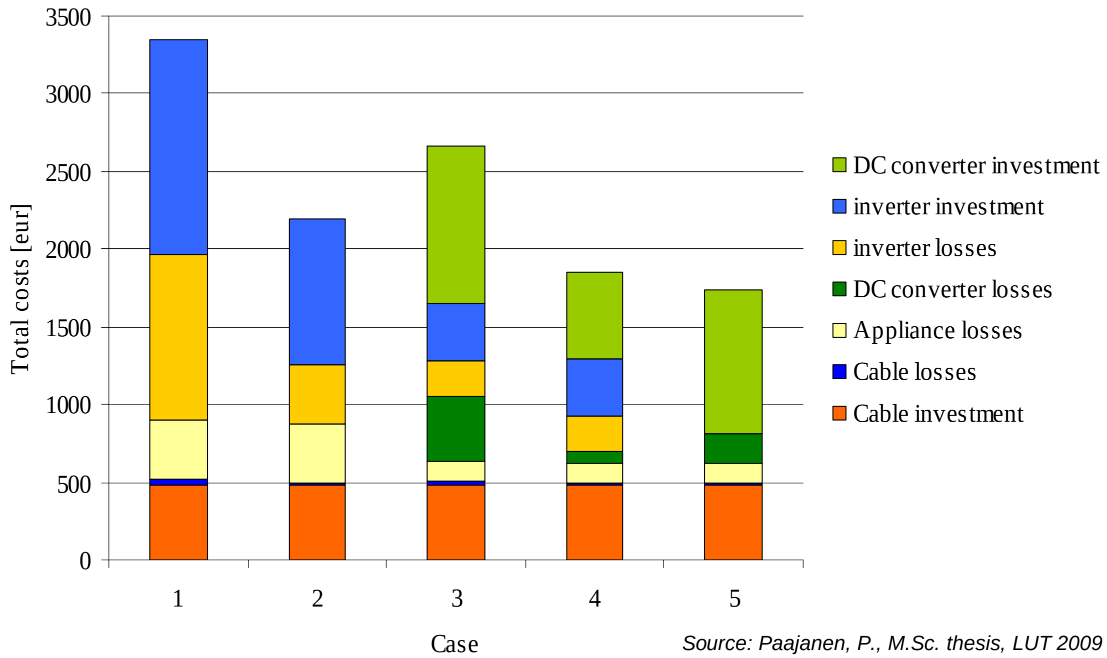
LVDC in residential buildings





- Internal DC networks reduce the total costs of distribution and improve energy efficiency
- Cost optimum leads also to energy efficiency optimum

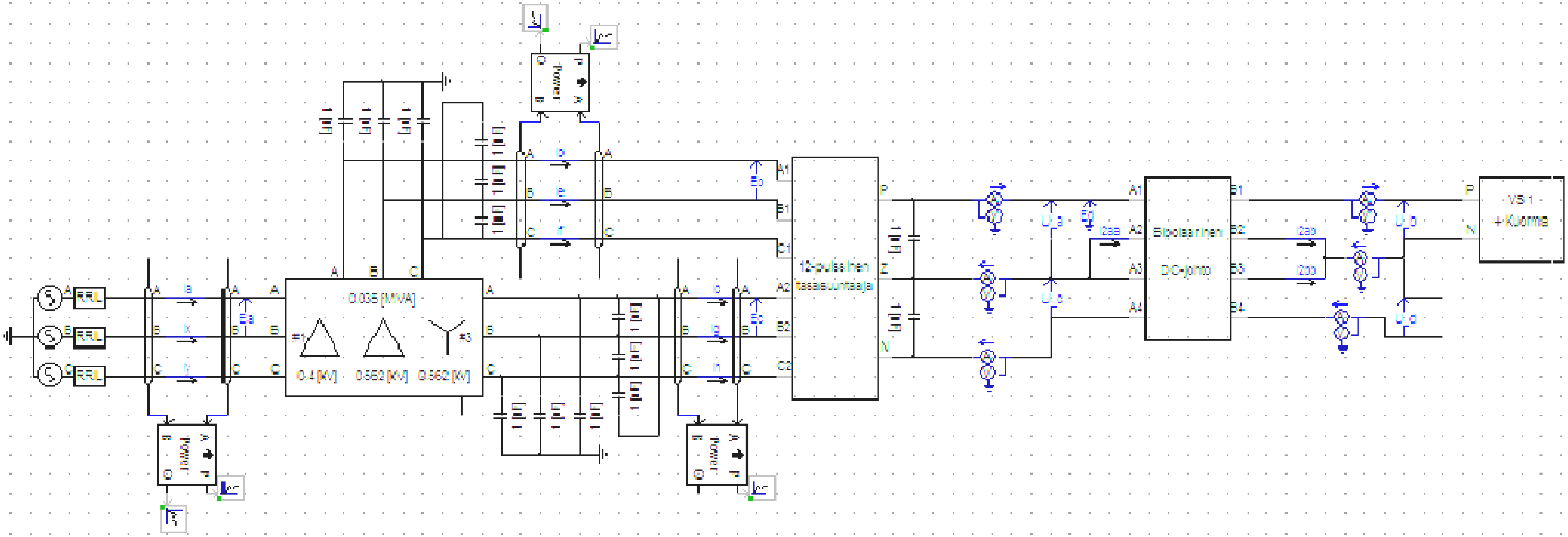
- Losses and investments of the power electronic devices are in a decisive role when comparing different distribution systems



Source: Paajanen, P., M.Sc. thesis, LUT 2009

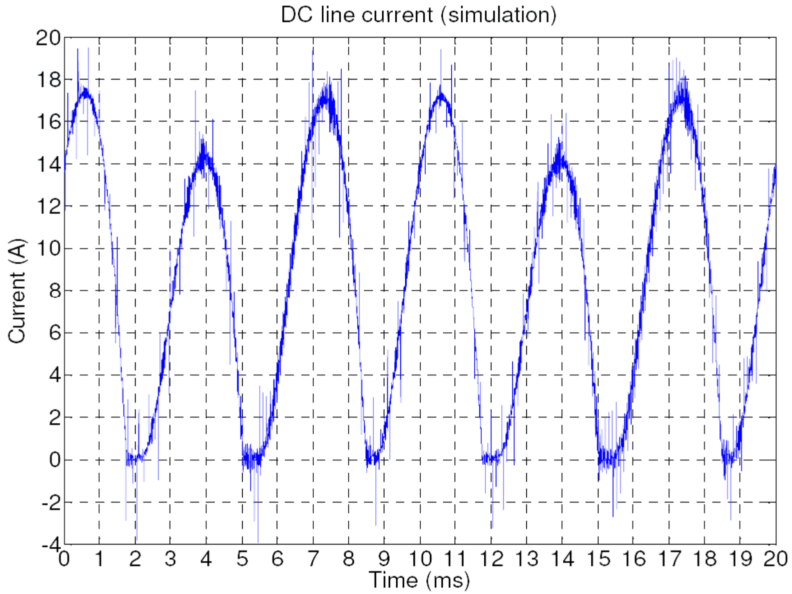
Simulation models

– **EMTDC/PSCAD**

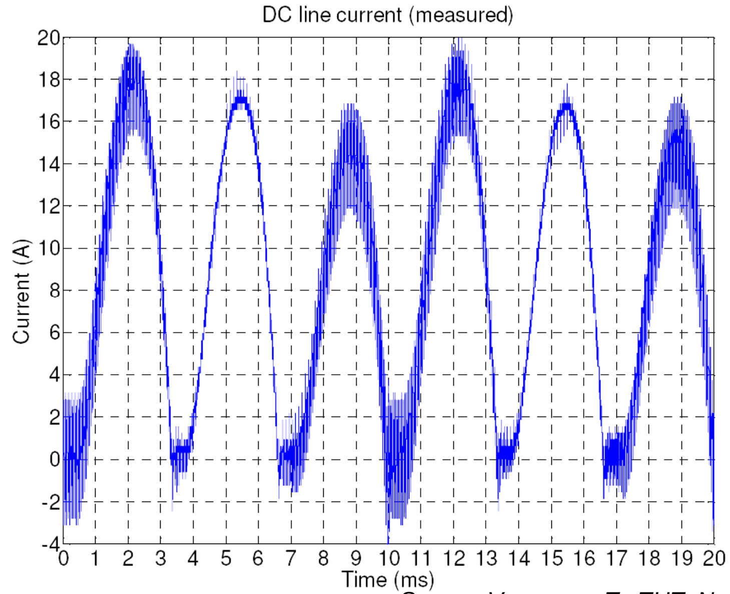


Simulation models

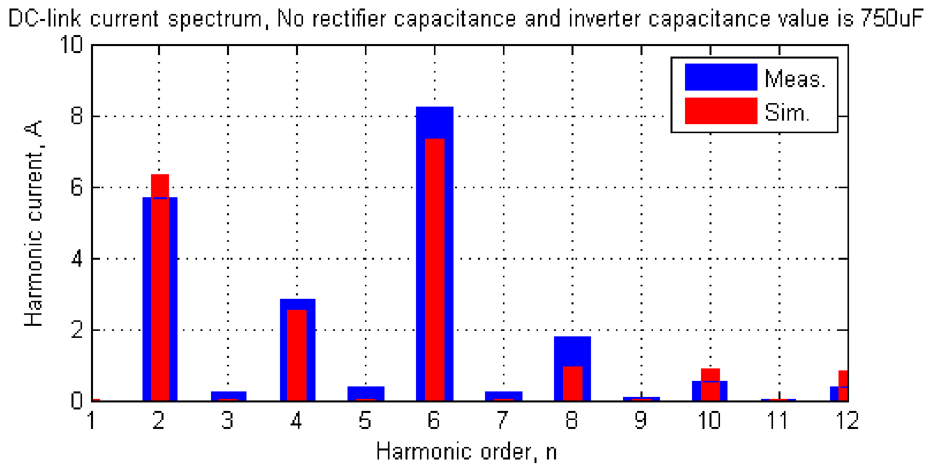
– **Validation against measurements crucial**

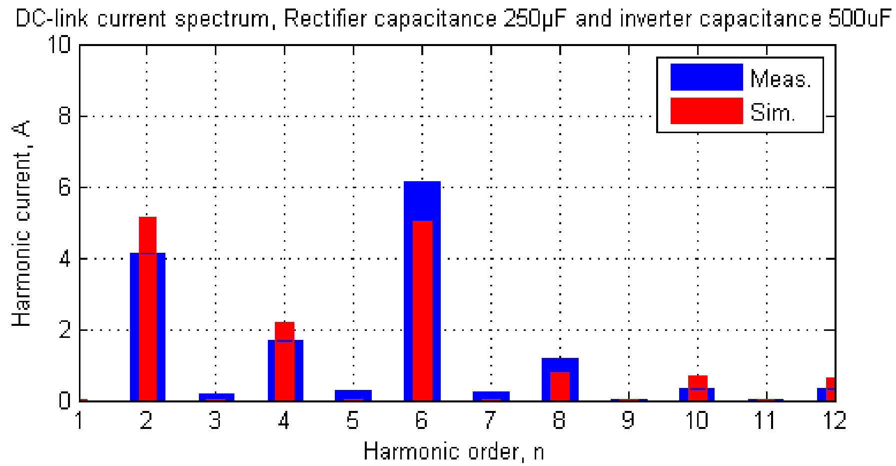


$I_{AVE} \approx 8{,}1$ A
$I_{RMS} \approx 10{,}0$ A



Source: Vornanen, T., TUT, Nordac 2010

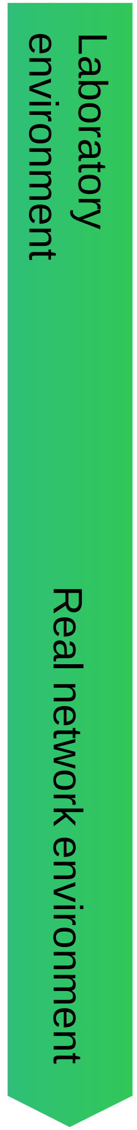




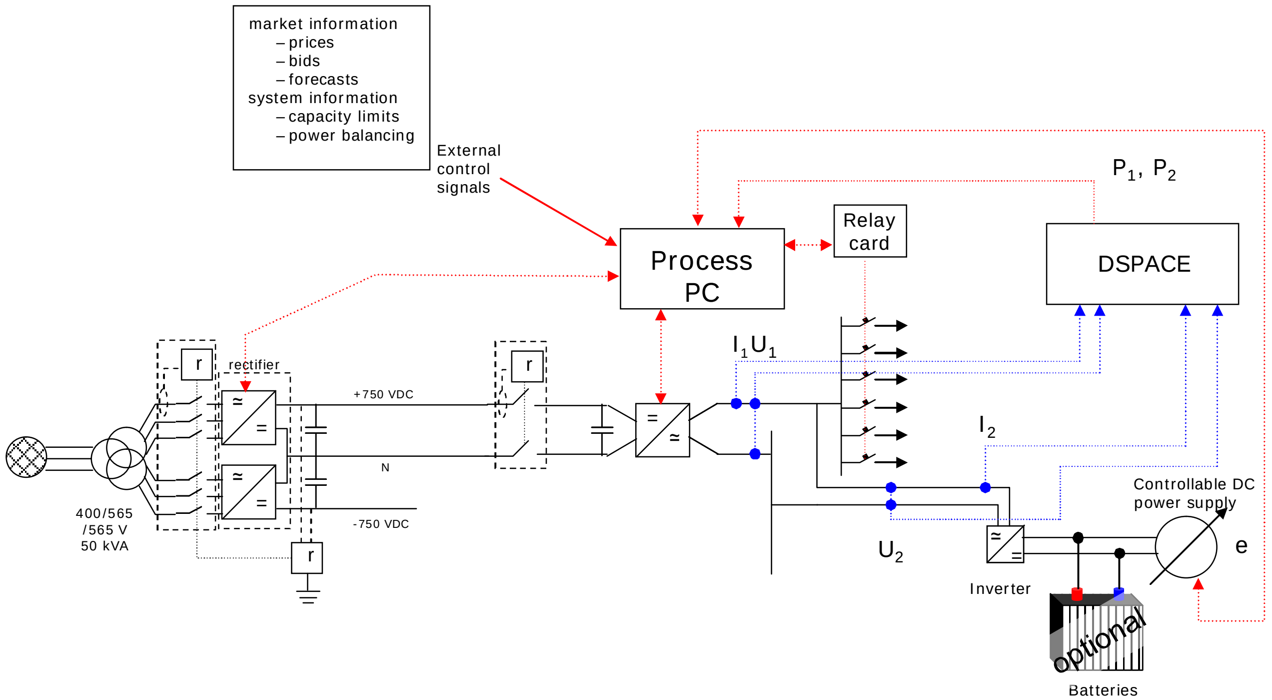
Objectives for research platform development

- **Provide test environment for technical solutions, functionalities, analysis methodology and design methods of LVDC technology**
- **Study implementation of research results in practical environment**

- **Provide feedback for component development and for practical product development**
  - Operation in variable surrounding conditions and equipment reliability
  - Suitability of mechanical structures from installation and maintenance perspective
  - Protection against electromagnetic interferences and fields
  - Co-operation with interconnected systems
- **Integration with existing network supervision and management systems**
- **Commission inspections and authorised approvals of structures**
  - Verification of electrical safety-practical environment hazard voltages and currents
  - Installation documentation, electric work safety and warning signs
- **Feedback for standardisation development**
- **Customer feedback**



Laboratory research platform

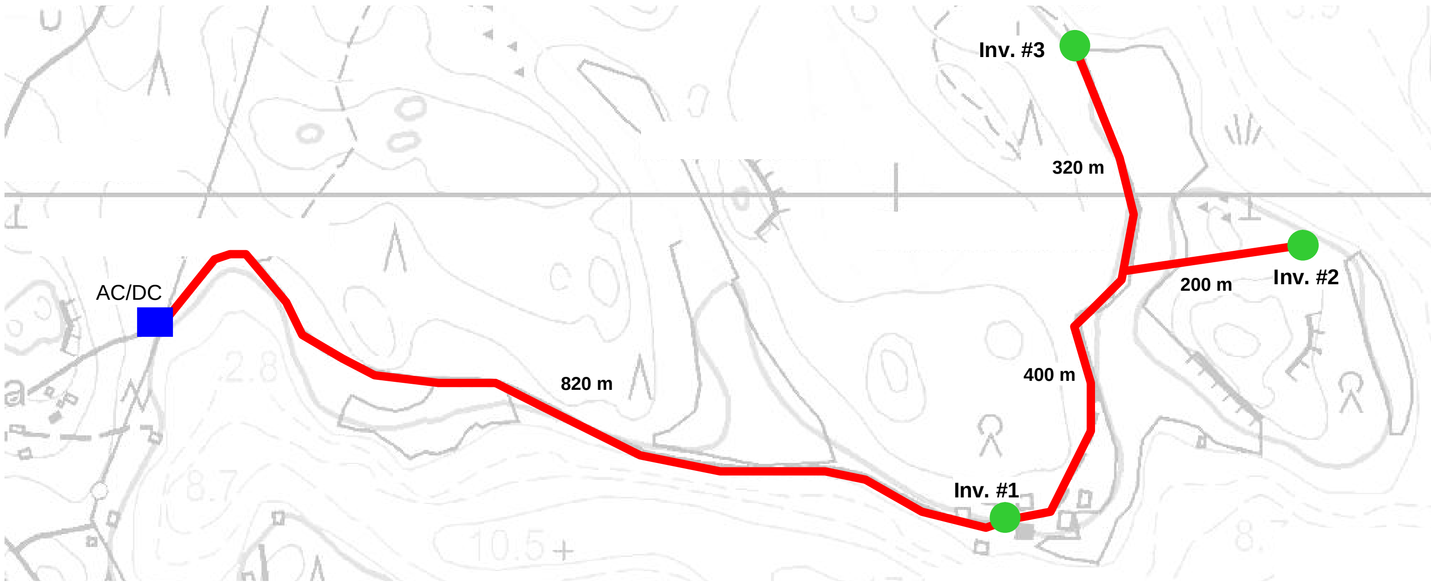


– **50 kVA 400/565/565 V supply transformer**
– **6-pulse diode bridge and 6-pulse half-controlled thyristor bridge rectifiers**
– **200 m DC cable, AXMK 4x16**
– **Two single-phase inverters without galvanic isolation transformers**
  – 160 A (inv. 1) and 75 A (inv. 2) IGBT modules
  – Two TI DSP control boards and dSPACE control environment

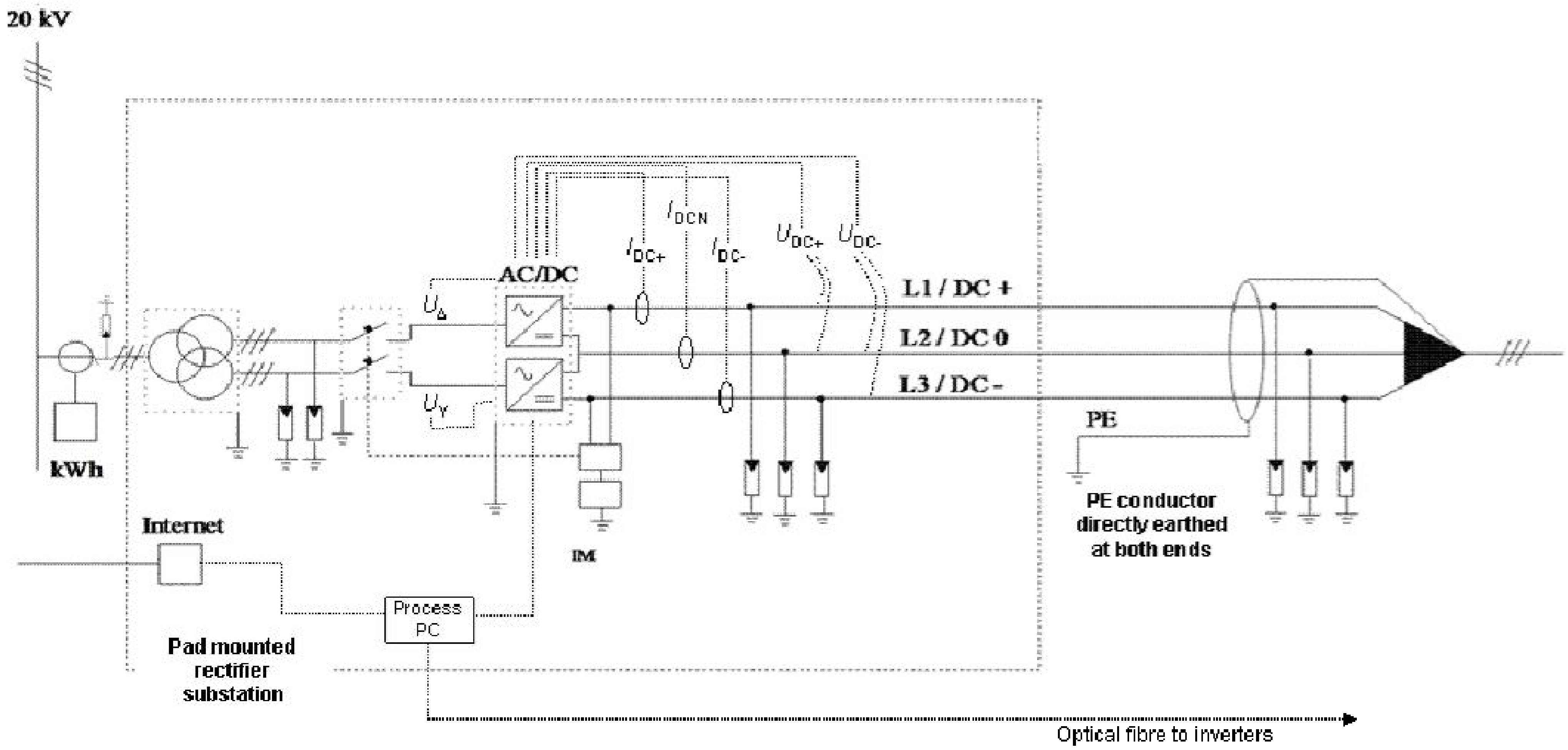
– **Entire system isolated from earth (IT)**
– **SMA Hydro Boy 1 kVA converter**
– **Serial bus controlled DC power supply**
– **Serial bus controlled relay board**
– **Seven contactors for resistive load control**
– **Artila Matrix 512 embedded PC for higher level control and data communications**
– **Required protection devices and contactors for fault testing**

Practical environment research platform

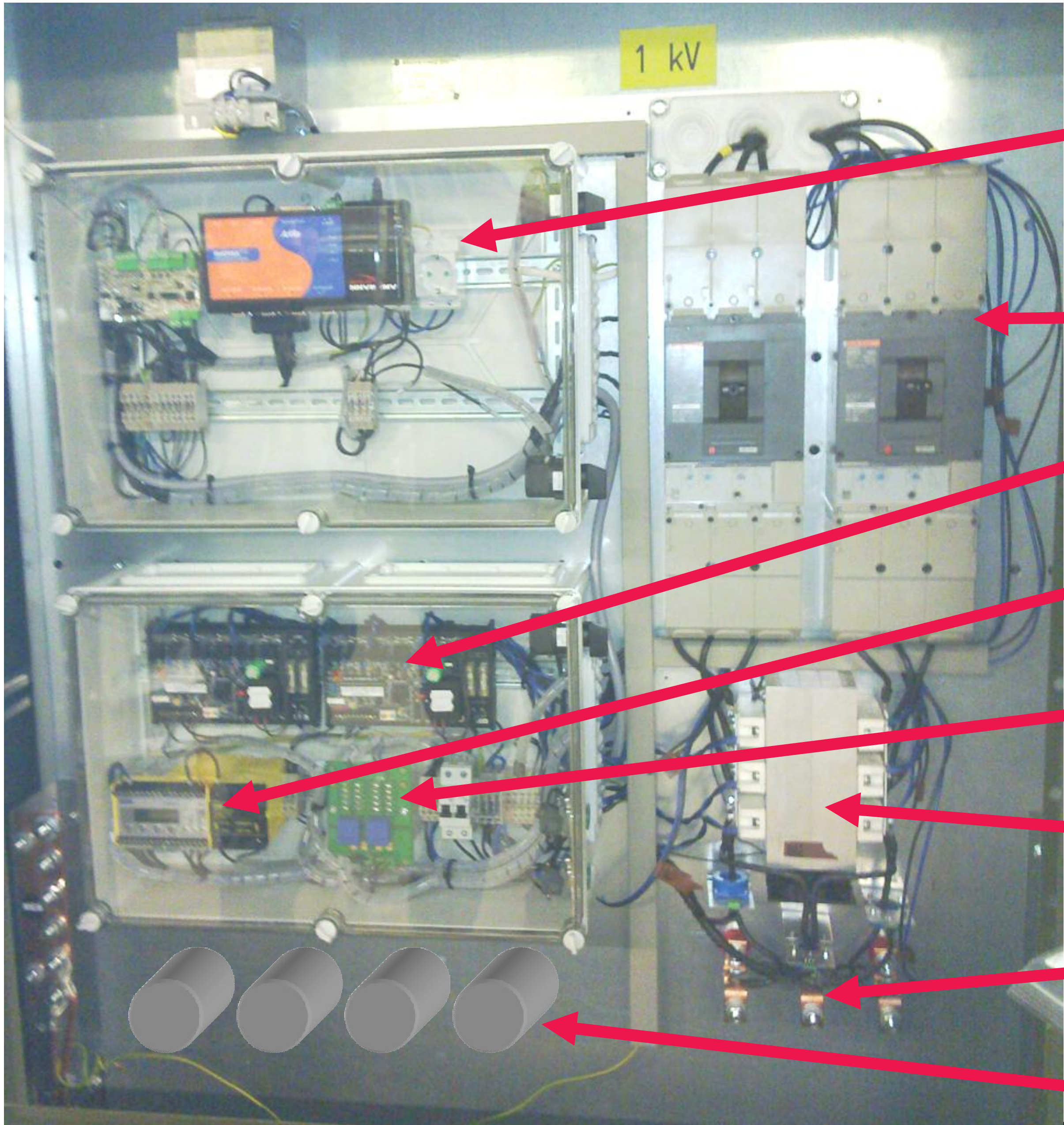
- **Co-effort of Suur-Savon Sähkö Ltd. and LUT, started in 1/2010**
- **Installation environment**
  - Developing recreational dwelling and detached house area
  - approximately 2 km of underground cabled network
  - in first phase 4 customers, fed by 3 inverters
- **Research platform for testing and developing both DC technology and interactive distribution network functionalities**
  - Real-environment practical component and functionalities testing
  - Development needs of components and feed back of system operation
  - Development needs of installation techniques and inspection methods



Practical environment research platform
System layout – Rectifier substation



Practical environment research platform
System layout – Rectifying substation



Process PC, system control board and communication

Main circuit breakers

Thyristor controllers

Insulation monitoring

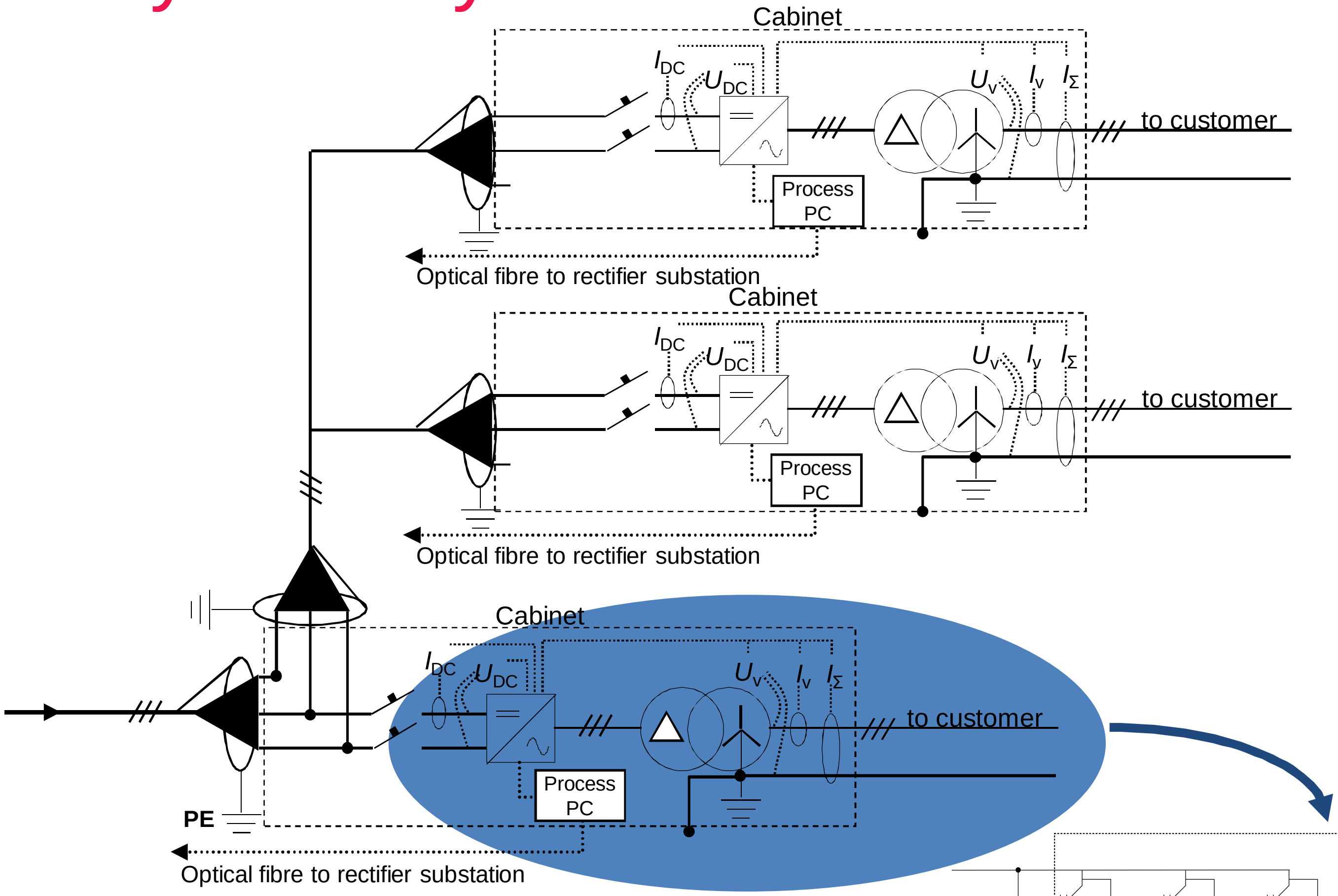
Measurement board

Thyristors

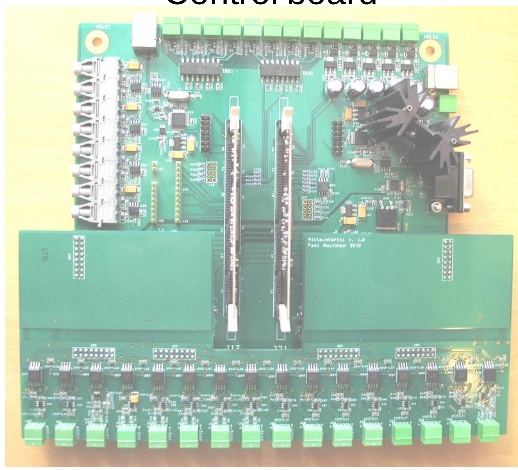
DC-output

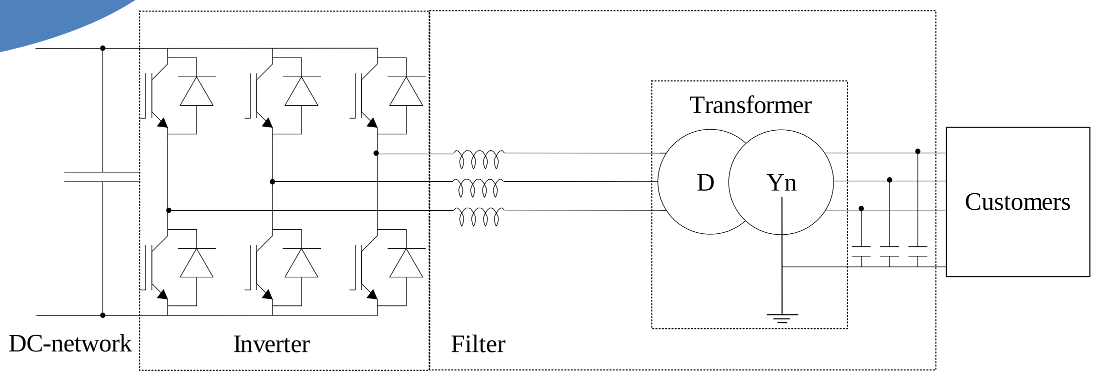
DC capacitors (not yet installed)

Practical environment research platform
System layout – Inverter substations



Control board





Further research

- **Laboratory research platforms for LVDC technology**
  - Testing and prototyping new technical solutions
  - Verification of active functionalities
  - Benchmarking of converter solutions
- **Practical environment research platform – rural LVDC networks**
  - Testing of the LVDC technology in actual installation surroundings
  - Guidelines for system installation and inspections
  - Public opinions and feed back from electricity end-users, DSOs and other related industry
- **Analysis and development of LVDC technology**
  - Development of technical solutions and algorithms for different applications of the LVDC distribution
    - Optimal system constructions for versatile applications
    - Optimal control strategies for converter and system control in different operational conditions
  - Improvement of the technical and economical performance of the LVDC system by the means of converter technology and network configurations
    - Development and analysis of converter topologies with and without galvanic isolation
    - Determination of measures for improving energy efficiency
    - Solutions for ensuring electric safety during operation, maintenance and installation
  - Development of calculation algorithms for network management, system analysis and for different planning tasks
    - System modelling and development of analysis methodology
    - Development of methods and guidelines for optimisation of the LVDC system structures and components
    - Development of methods and tools for the LVDC system supervision
- **Connection of DG and energy storages into LVDC network**
  - System control needs and algorithms
  - Connection interface development
- **Intelligent protection and active management of LVDC system**
  - Protection function development
  - Integration of protection system in converters and efficient application of ICT

LVDC - Pros and Cons

+

1. Full control of customer's supply voltage
2. Improved LV transmission capacity
3. Less distribution transformers and MV lines
4. Improved supply security
5. Reduced risk of storm caused blackouts (in OHL networks)
6. Reduced total costs of distribution networks
7. Decreasing cost development of power electronic components
8. Flexible connection point for DG and storages
9. Natural basis for island operable microgrids

⇨ Backbone of smart distribution

-

1. Complicated system construction
2. Additional losses due to converters
3. Increased need of maintenance
4. Shorter life-time of components
5. Lack of standardisation
6. New technology without decades long experiences

CLEEN
Cluster for Energy and Environment

sgem
Smart Grids and Energy Markets

Open your mind. LUT.

Lappeenranta University of Technology