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Cluster for Energy and Environment

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Lappeenranta University of Technology

Future Grid Architectures - LVDC

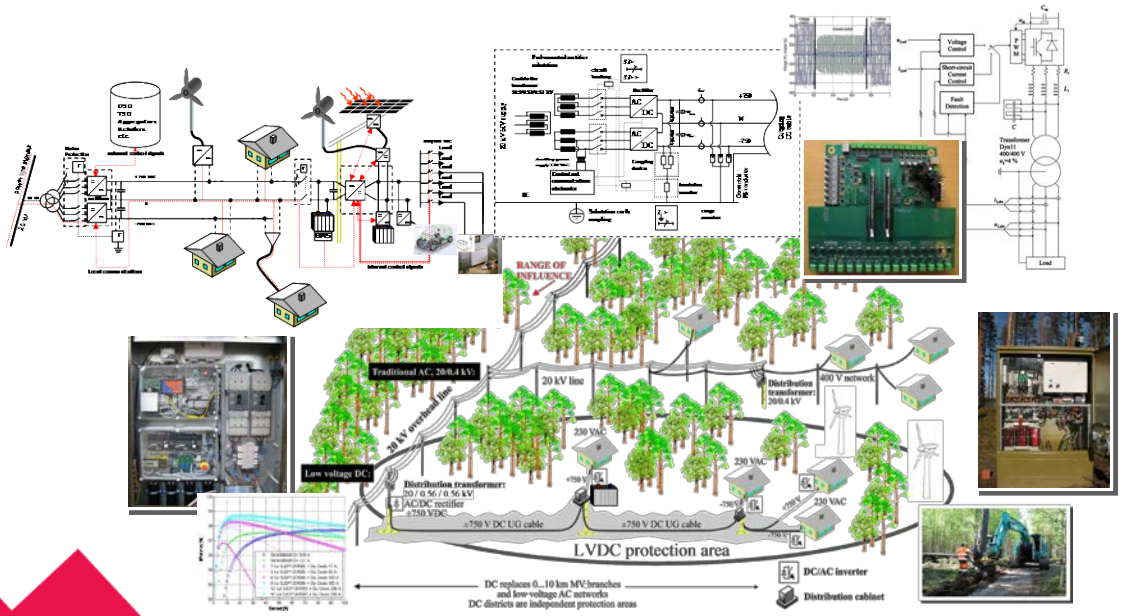
sgem
Smart Grids and Energy Markets

WP2: Future Infrastructure of Power Systems

sgem
Smart Grids and Energy Markets

Future Grid Architectures

LVDC



Research Groups of
Tasks 2.4 and Task 2.5

Definition of Smart Grid

- "*Electricity networks that can intelligently integrate the behaviour and actions of all users connected to it - generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies. A smart grid employs innovative products and services together with intelligent monitoring, control, communication, and self-healing technologies*"
    - EC, Strategic Deployment Document for Europe's Electricity Networks of the Future, 2010

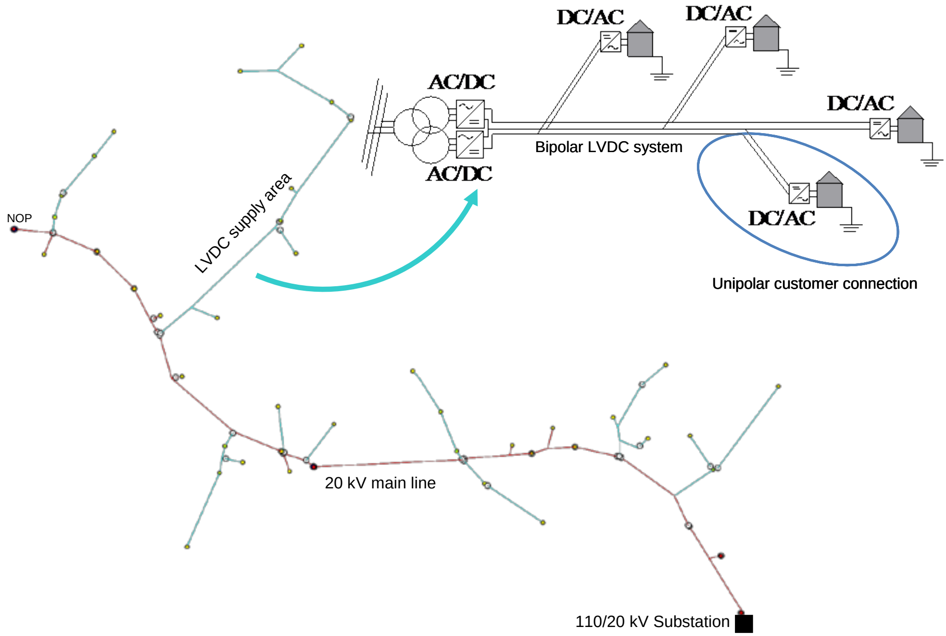
- Electric power system that utilizes information exchange and control technologies, distributed computing and associated sensors and actuators, for purposes such as:
    - to integrate the behaviour and actions of the network users and other stakeholders,
    - to efficiently deliver sustainable, economic and secure electricity supplies
        - (1/2173/FDIS Amendment 1 to IEC 60050-617: International electrotechnical vocabulary - Part 617: Organization/market of electricity)

Introduction to LVDC

- Background
  - Even though the Smart Grids is mainly development of intelligent applications and related ICT, the biggest 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

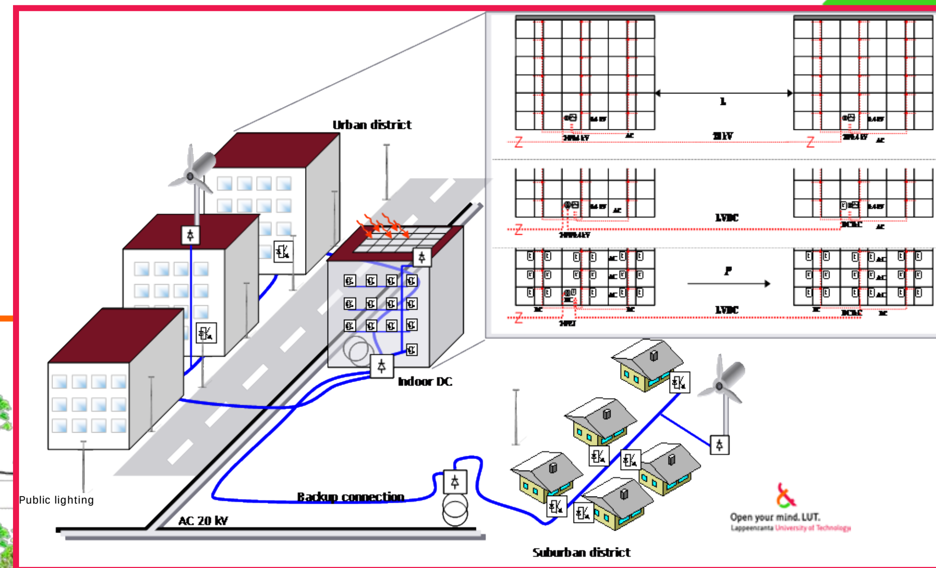
Concept of LVDC Electricity Distribution

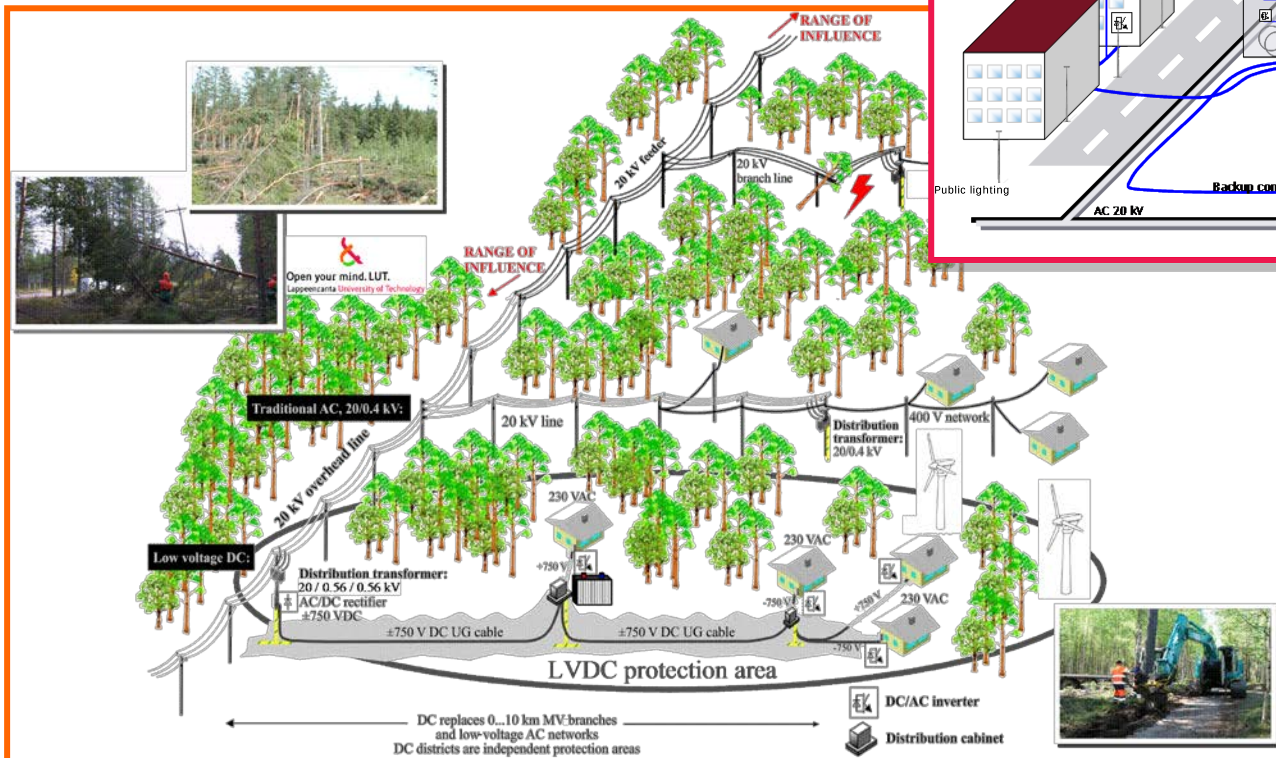
- Rated voltage range
  - 75 – 1500 VDC (LVD 2006/95/EC)
  - 120 – 1500 VDC (IEC)
- An LVDC distribution system comprises power electronic converters and DC connection between the converters
  - The entire low-voltage network is realised with DC system
  - End-customers have either a direct DC connection, 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
  - Low costs of constructing and operating the distribution network



→ **“Smart” grid technology**

LVDC in Rural and Urban Environments





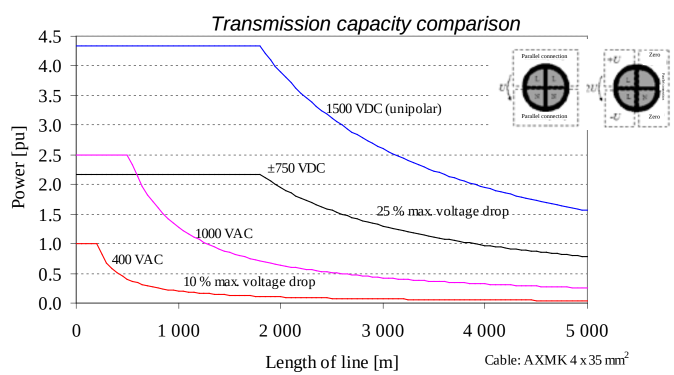
Technical Properties of Utility Grid LVDC

- Technical properties
  - Rated DC voltage: ±750 VDC, 1500 VDC
  - 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, reality in voltage ~ ±2%)
  - Communication between all converters
  - Techno-economic power transmission capacity <500 kW up to 10 km

- 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

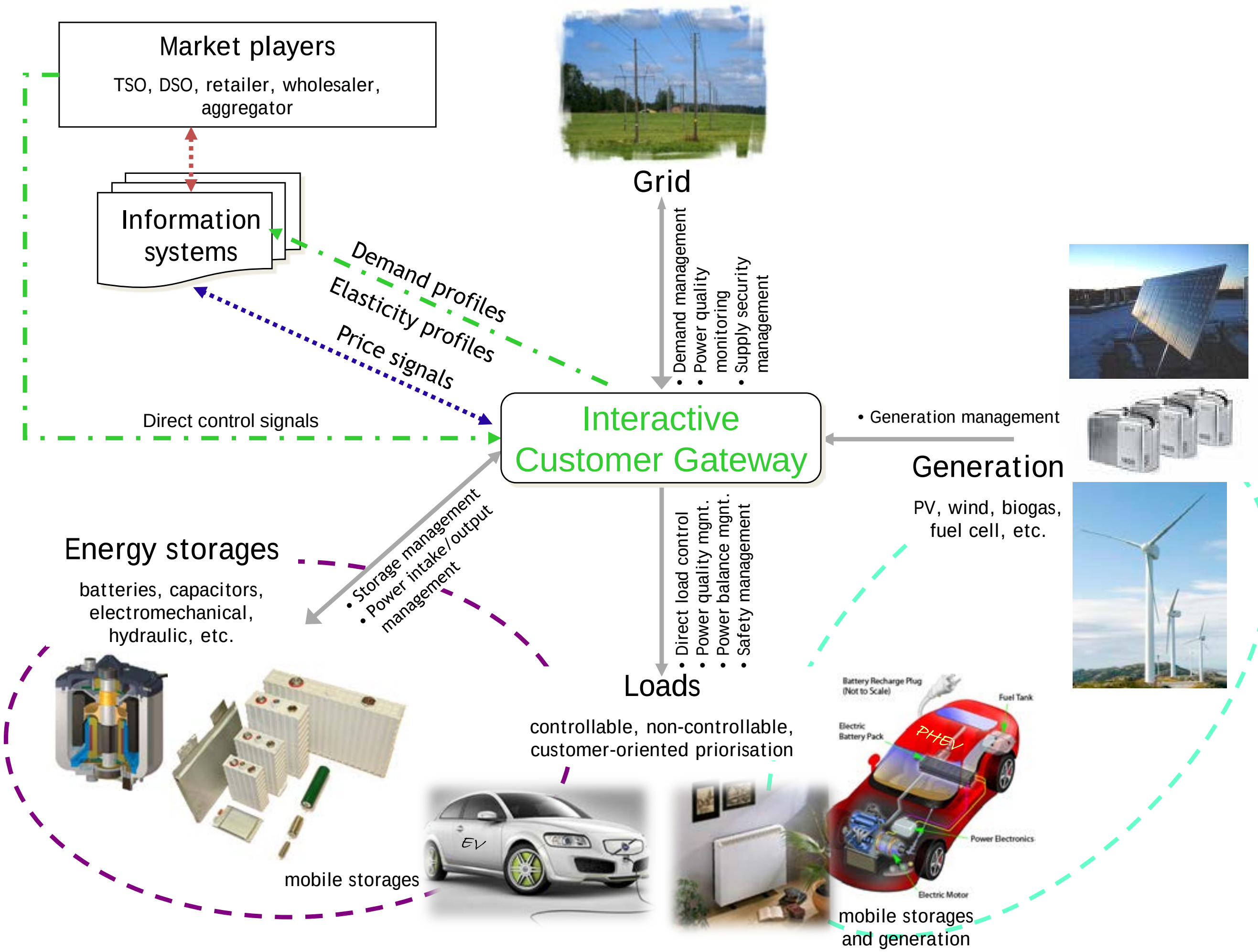
- Interactive functionalities
  - Continuous system supervision
  - Active power quality supervision
  - Grid side power demand control
  - Control of ES charging/discharging
  - Market information exchange

- Optional features
  - Un-interruptible power supply during outages
  - Constant power flow control
  - Intentional islanding
  - PFC in MV network interface



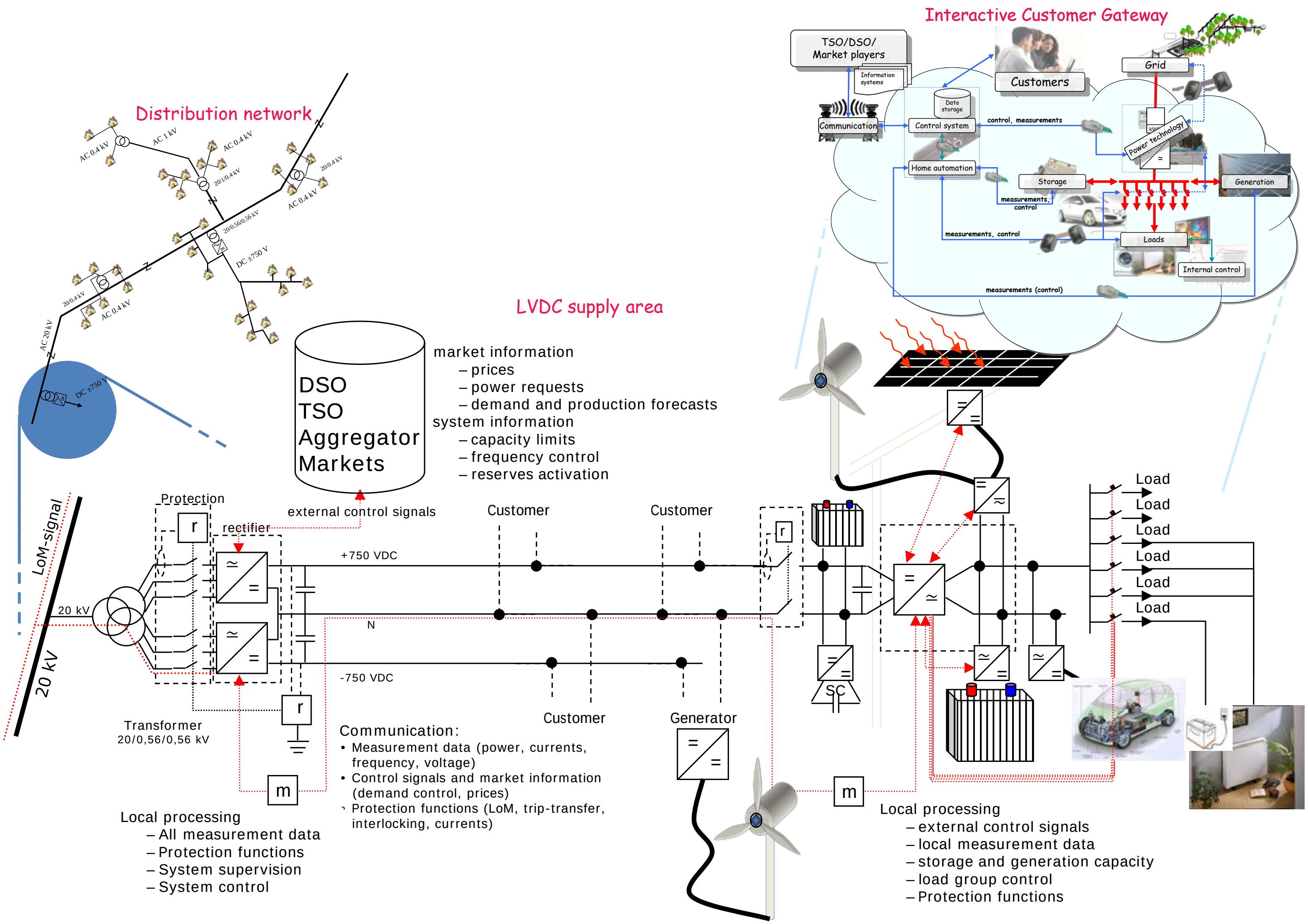
Integration of Smart Grid Functionalities

Interactive Customer Gateway – Activation of Electricity End-users



LVDC Microgrid Concept

Implementation of Interactive Customer Gateway



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

"Radical changes are expected in technology, business models and the functionality of electricity distribution. Based on innovative technical solutions and new business models, there are opportunities to develop active electricity distribution systems that tolerate disturbances, are safe, and have positive impacts on the electricity market development."

Hyphothesis of "Revolutionary Electricity distribution System" project 2008-2011 (Academy of Finland, Sustainable Energy program)

Research Topics

System
- Concepts
- Control and supervision
- System enginee-ring

Electric safety
- Safety hazards
- Protection against electric shock
- Protection of equipment and property

Converters and equipment
- Network compo-nents
- Converter topologies
- Converter control
- Filters

Research platforms
- Laboratory
- Field environ-ment

Modelling and simulation tools

Energy and cost efficiency

Test environments

Public power systems | In-house installations | Safety requirements | Applicability of existing components | Verifi-cation | Practical experiences

Distribution | Microgrids | Island systems | Application environment | Converter bridges | Control boards | Laboratory hardware

Voltage levels | Application potential | Protection system alternatives | Measurements | Design specifications | Field test setups

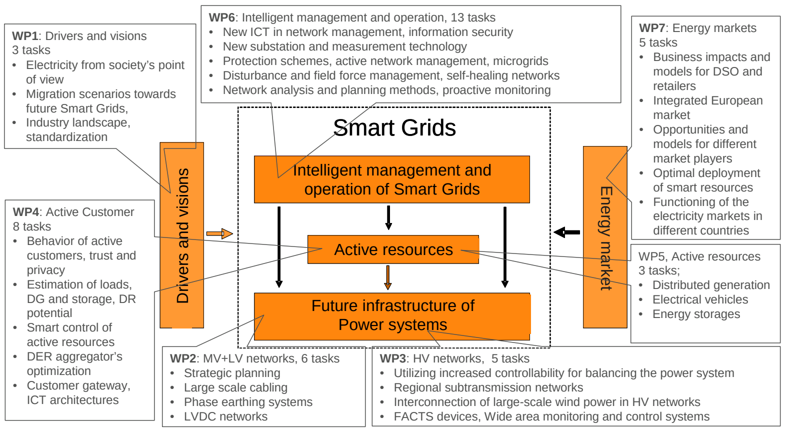
Analysis methods | System control principles | Protection algorithms | Voltage quality | Passive and active filters | Demonstrations

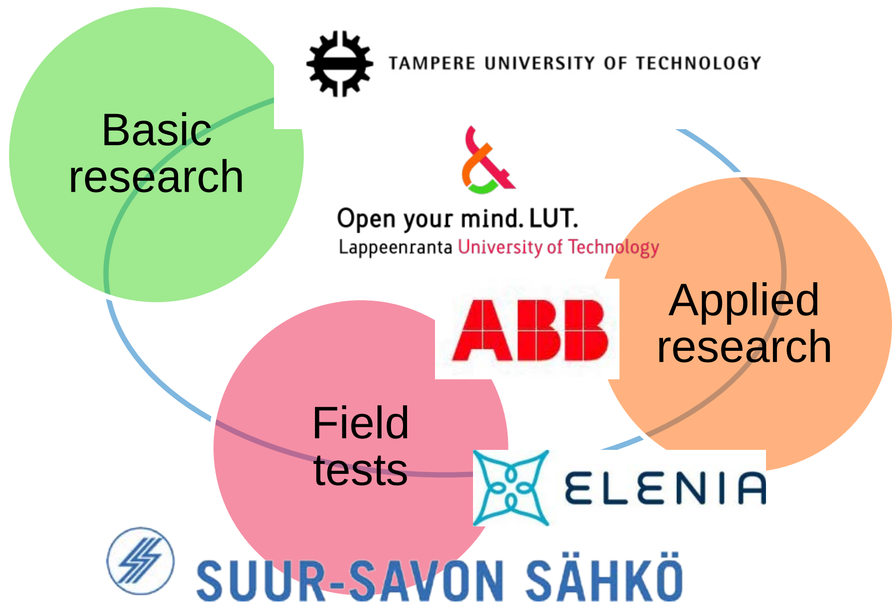
Network topologies | Design guidelines | Communications and converters in protection | Control algorithms | End-user feedback

System standardisation

LVDC in SGEM Program

- WP1: Drivers and vision of SGEM
  - Smart Grid standardisation including LVDC
  - Participating into work of SESKO, GENELEC and IEC
- WP2: Future infrastructure of power systems
  - Development of converters and network structures
  - Analysis and design methods
  - Laboratory research platforms
  - Actual network environment research platforms
- WP4: Active resources; active customer, customer interface and ICT
  - Energy management systems and related ICT solutions
  - Integration of interactive functionalities into converters
- WP6: Management and operation of SGs
  - Electrical safety and protection in LVDC distribution
  - Microgrid management





Highlights – Research Platforms

- Test environment for technical solutions, functionalities, analysis methodology 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
- 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

Laboratory environment

Real-life network environment

Laboratory Research Platforms

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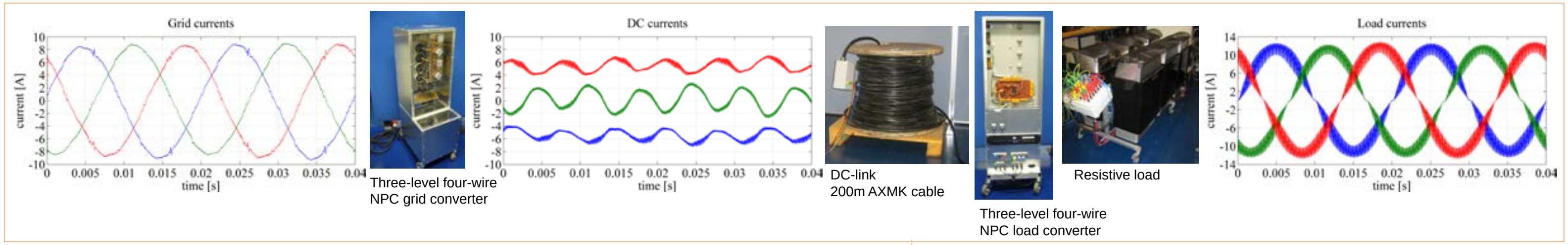
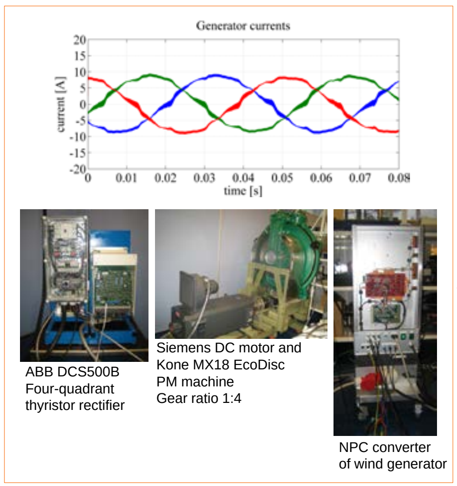
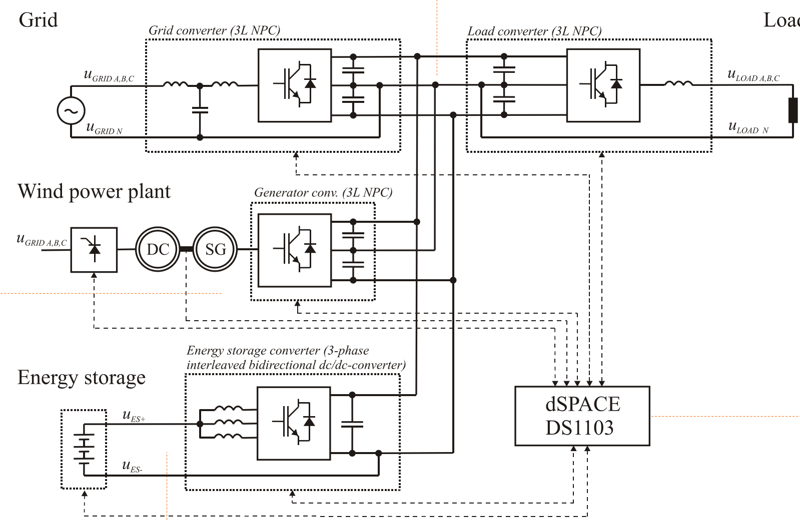
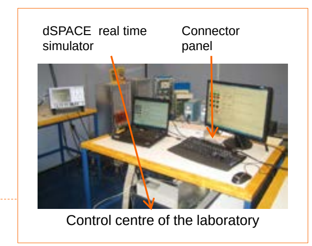
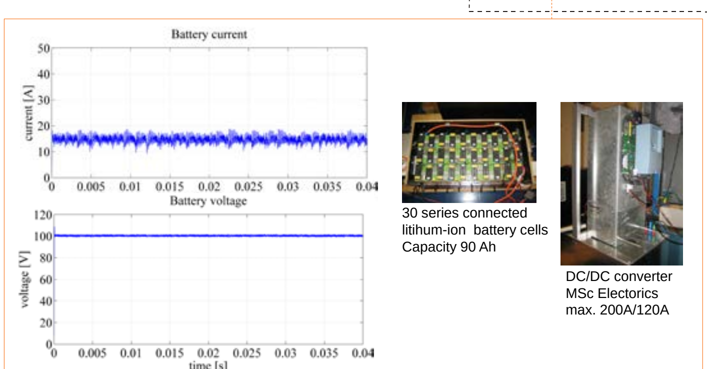






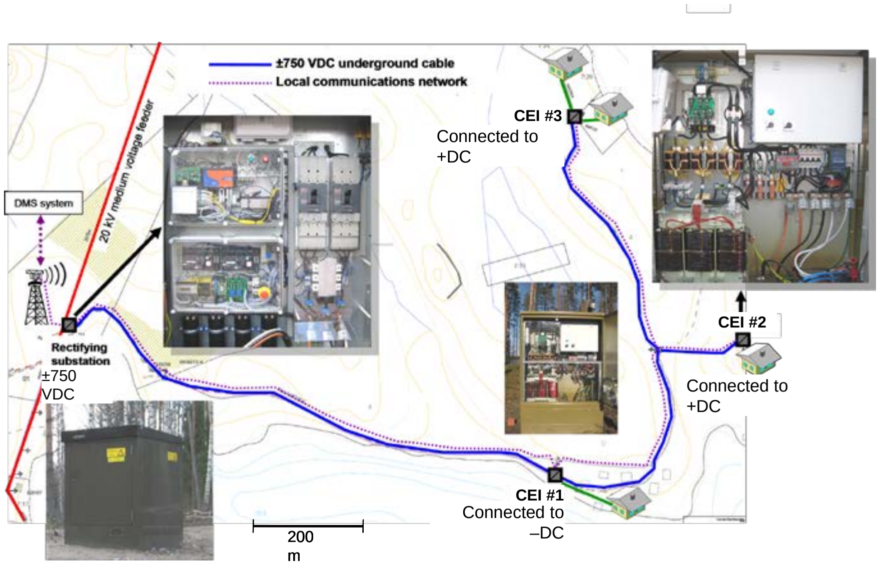




– Laboratory research environments have been realised both at Tampere and Lappeenranta

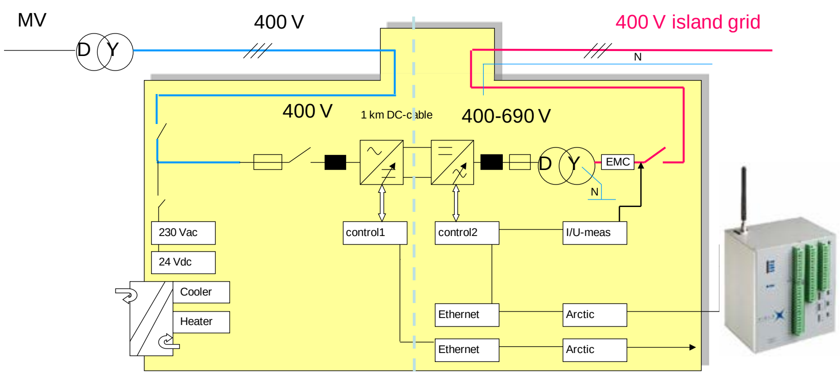
Field Installations

Field test site by LUT and SSS Oy



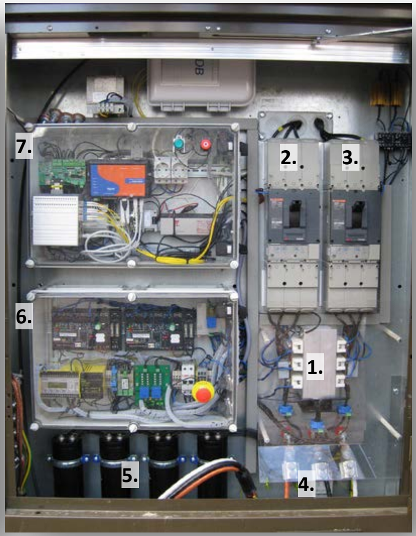
- 1.7 km bipolar LVDC network with three three-phase customer-end inverters installed in Suomenniemi
- Objective to test converter technology and collect experiences from LVDC distribution in whole
- In continuous 24/7 operation since June 2012, no major problems

Field test site by ABB and Elenia



- Installation of an island converter into a rural low voltage network in Orivesi
- Objectiven to test converter technology and study power quality in a converter fed network
- In operation since spring 2010, presently by-passed due to converter audible noise issues

Field Installations by LUT and SSS Oy



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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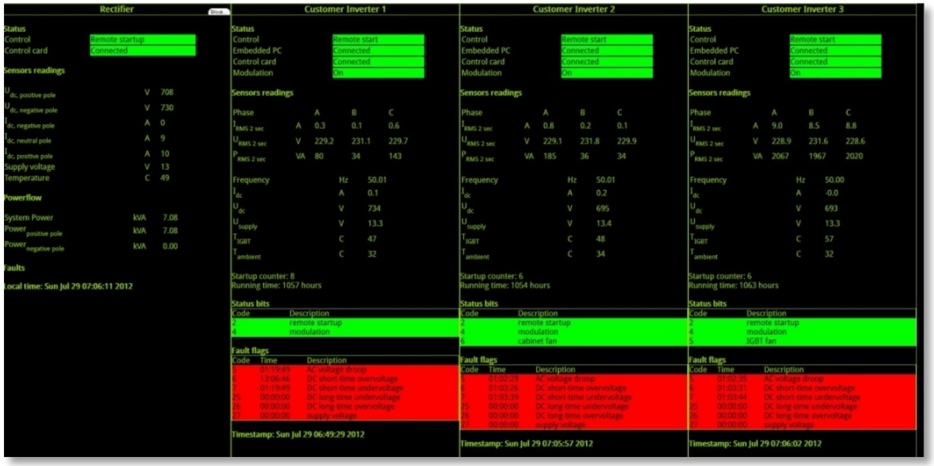
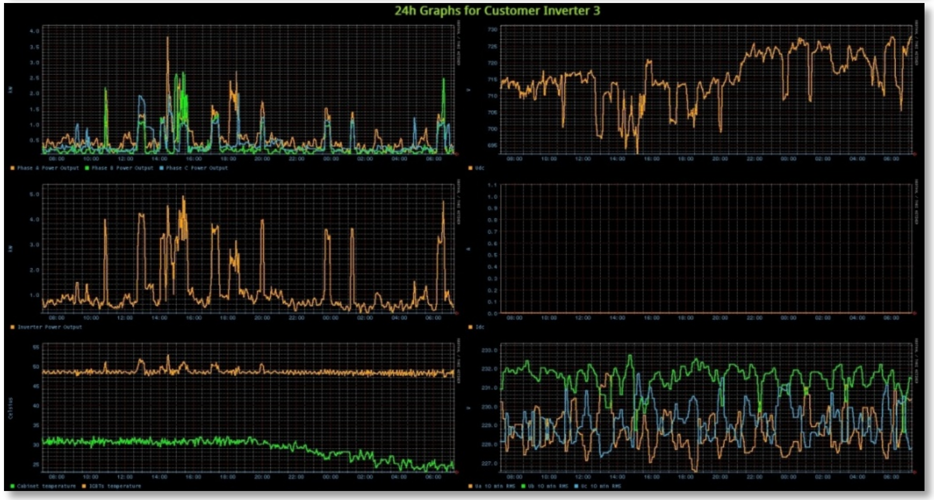
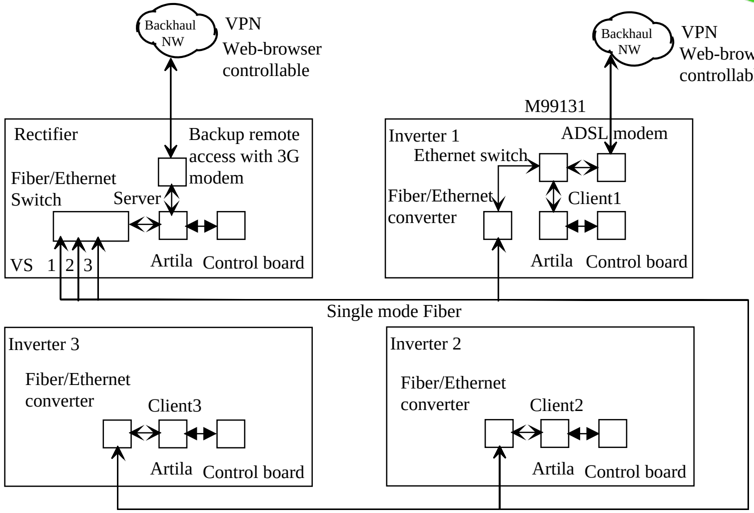
System Management

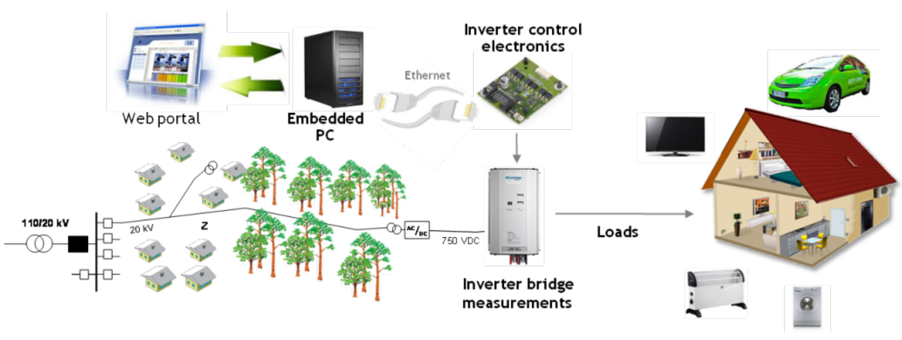
Web portal for monitoring and control







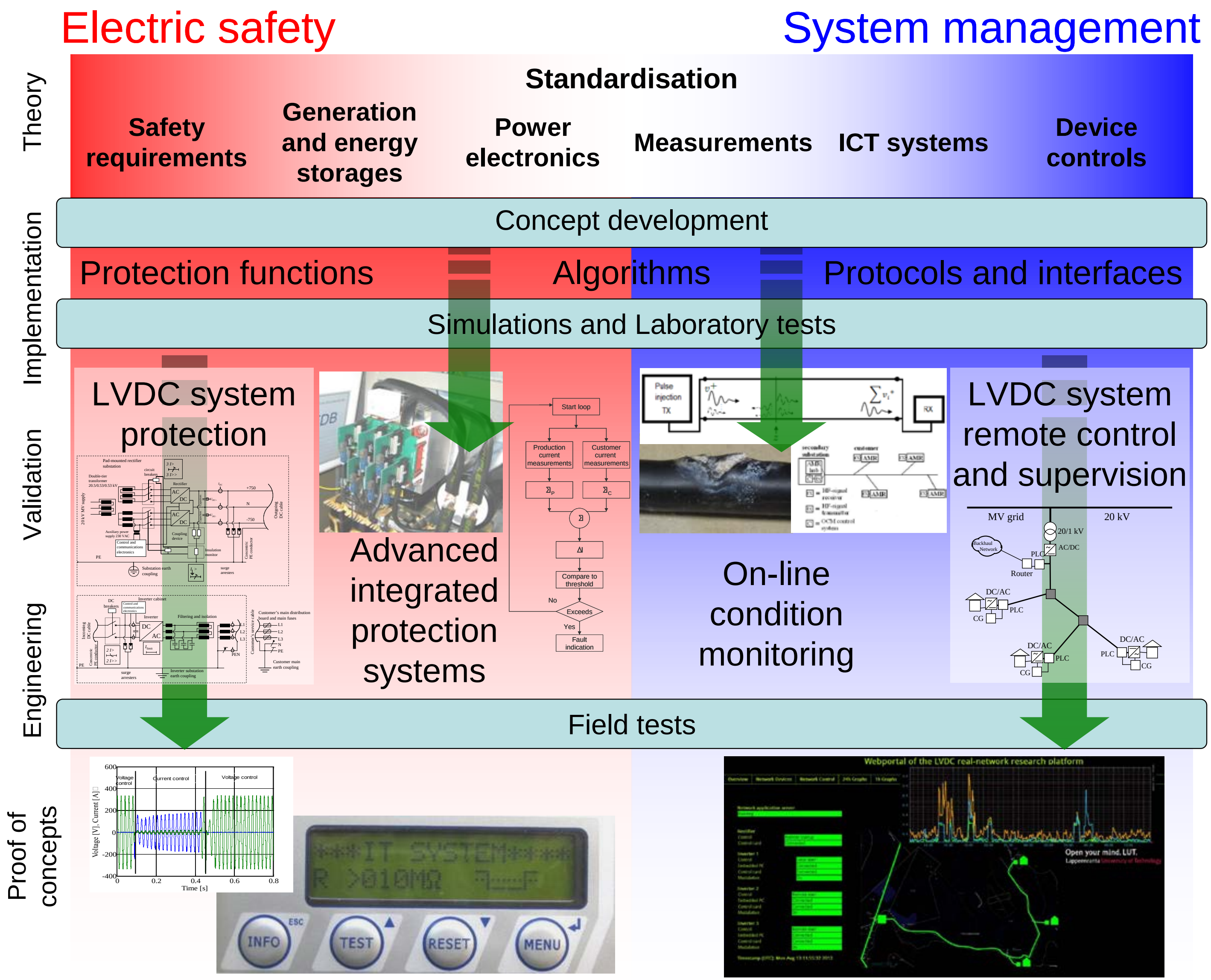
Local ICT-system



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

SUUR-SAVON SÄHKÖ

Protection and Supervision

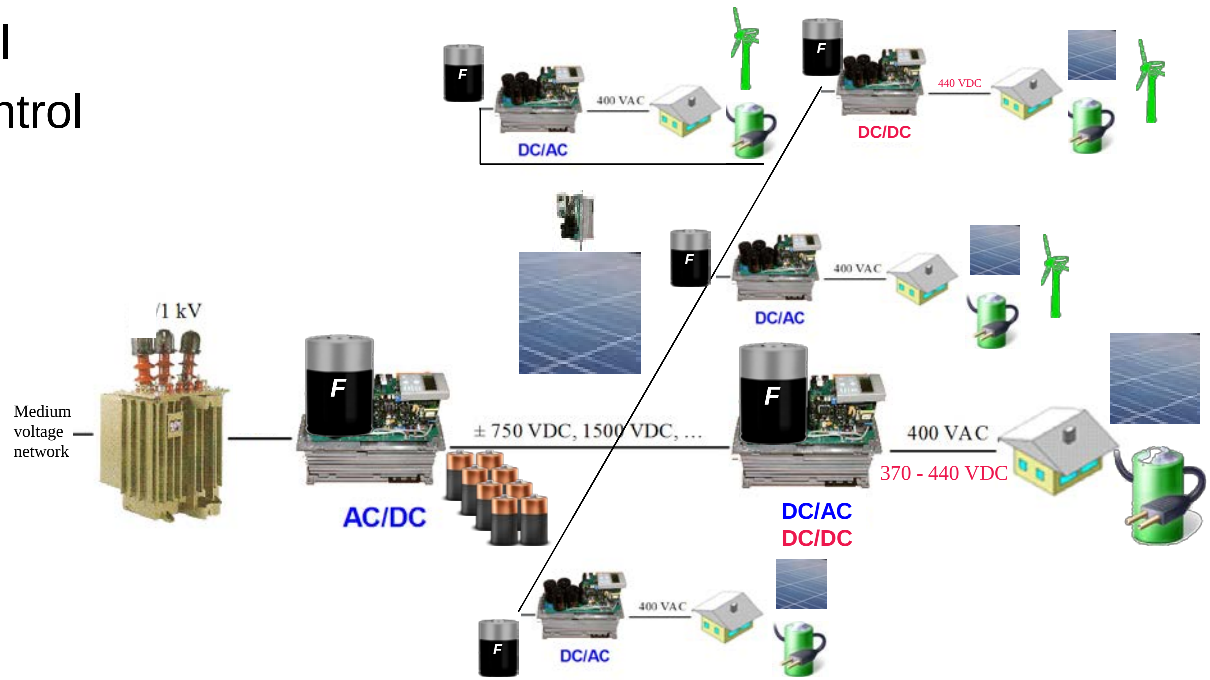


Commission Tests in April 2012




Field Installations - Next steps

- Continuous collection of user experiences
- Improvement of measurement data logging
- Implementation of disturbance recording system
- Updates to converter hardware and system controls
- Connection of energy storages and local generation
- Integration of microgrid controls
  - Island mode control
  - Market oriented control
- Standardisation issues

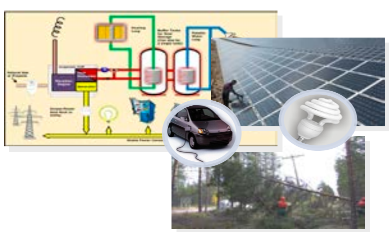


Strategic Planning View to LVDC

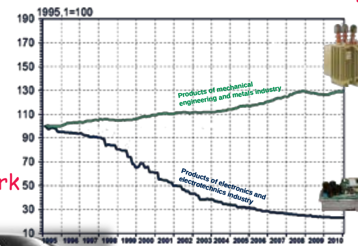
Environment
- Climate change
- Landscape issues
- Land-use issues
- Impregnants
- Electric and magnetic fields

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

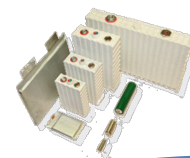
Society and socio-economics
- Safe use of electricity
- Reasonable pricing
- Supply security
- Energy efficiency actions
- Functional markets



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



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

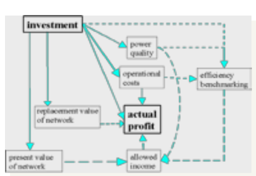


Customers
- Customer expectations on
  - **Quality of supply**
  - **Pricing**
  - **Functional markets**
- Changes in energy usage patterns
  - **Energy efficiency actions**
  - **Dynamic loads**
  - **EVs and DG**
- Equality
  - **pricing**
  - **service quality**

Role of power electronics in future electricity distribution infrastructure

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

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



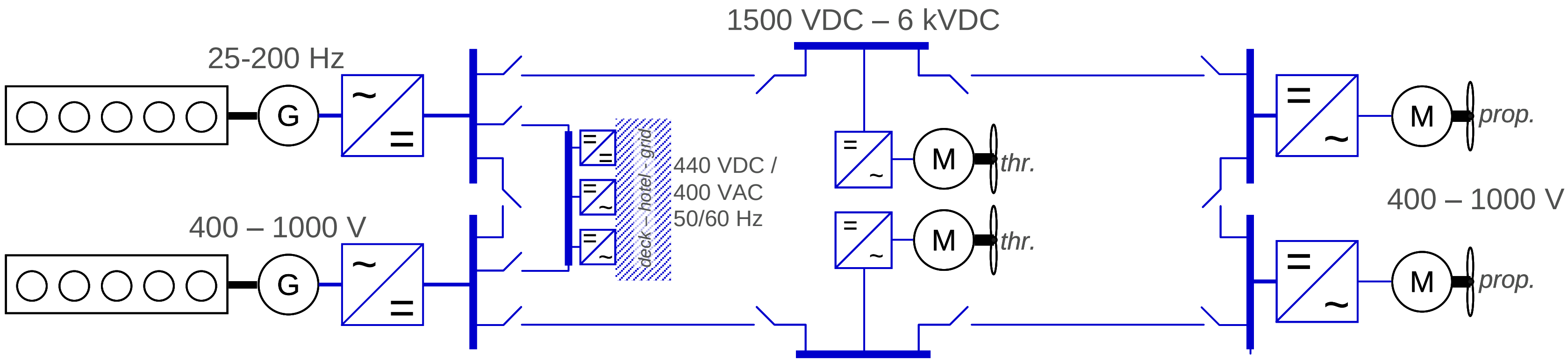
Regulation of network business
- Allowed profit regulation
- Quality of supply
- Cost efficiency
- Energy efficiency

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

Collaboration Between SGEM and FCEP

DC power systems in marine vessels



Pros

- Improves total energy and cost efficiency
  - High transmission capacity grid
  - Less high power AC/DC and DC/AC conversions
  - No high power transformers
  - Lots of generator design freedoms
- Natural coupling point for electric energy storages
- No voltage quality issues
- Easy to control - only voltage droop control required

Cons

- Importance of converters high
- Safety issues require galvanic isolation transformers for deck loads
- Requires DC circuit breakers
- No experience, reluctant customers?

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