Alexandre Oudalov, ABB Corporate Research, 2013-09-11

Santiago 2013 Symposium on Microgrids
New Technologies for Microgrid Protection

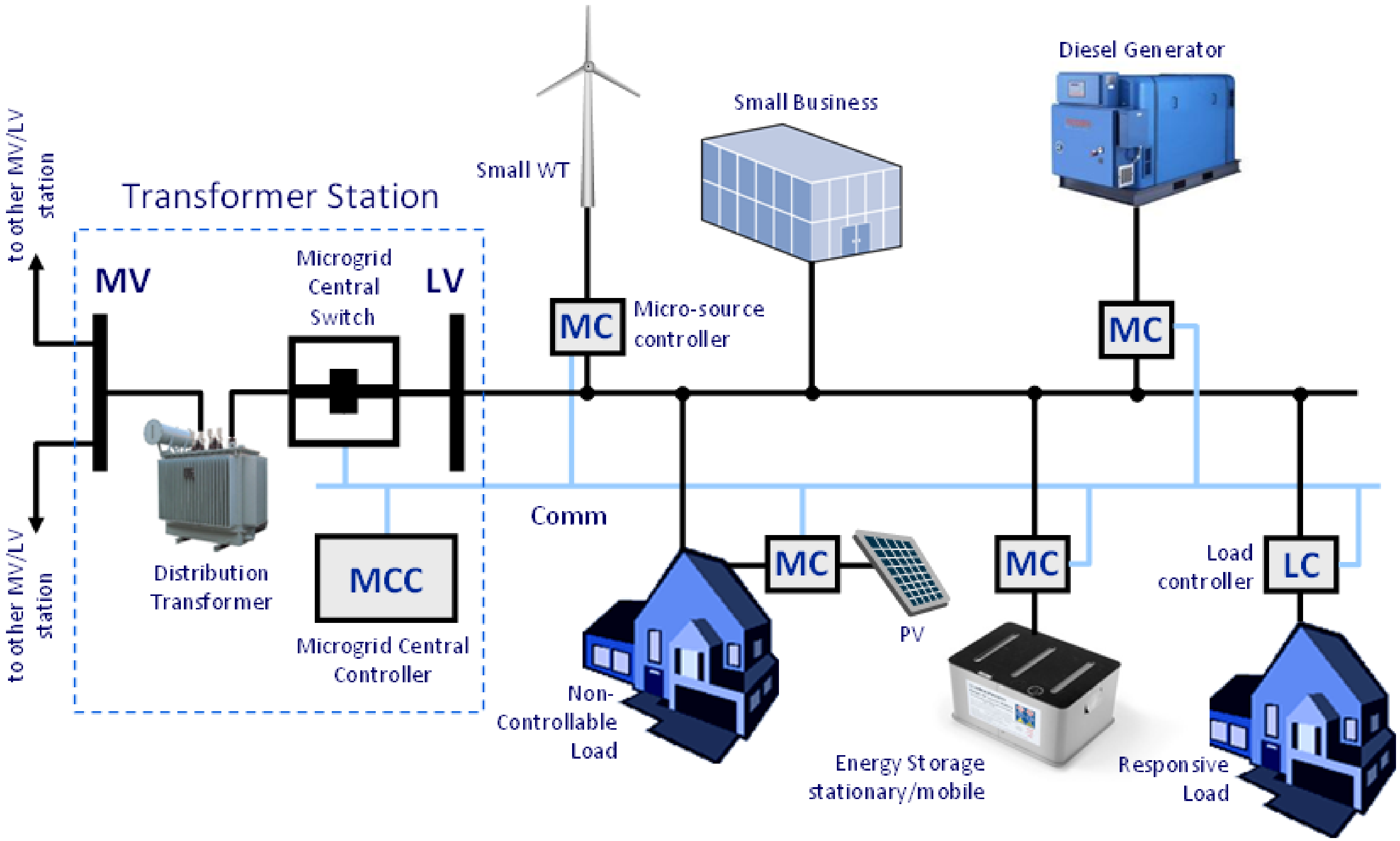
Power and productivity
for a better world™

New technologies for microgrid protection
Outline

- Introduction
- What?
  - Protection issues in microgrids
- How?
  - Adaptive protection solution
- Conclusions

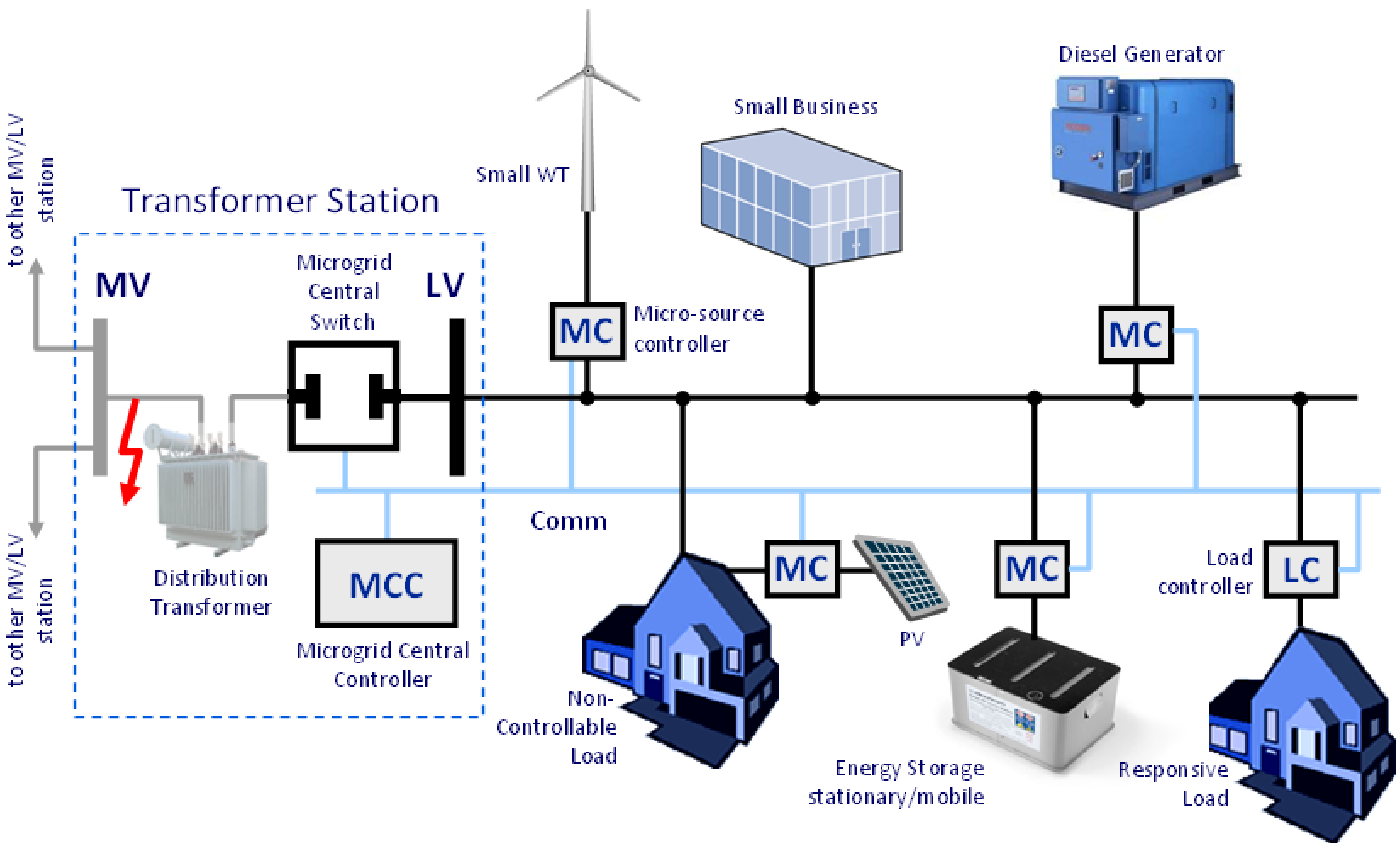
Credits: Dmitry Ishchenko (US), Hannu Laaksonen, Jani Valtari (FIN), Enrico Ragaini, Antonio Fidigatti (IT)

Microgrid protection
Grid connected and islanded modes



Protection must respond to both utility grid and microgrid faults
utility grid faults: protection isolates the microgrid from the utility grid as rapidly as necessary to protect the microgrid loads.
microgrid faults: protection isolates the smallest possible section of the feeder.

Microgrid protection
Grid connected and islanded modes



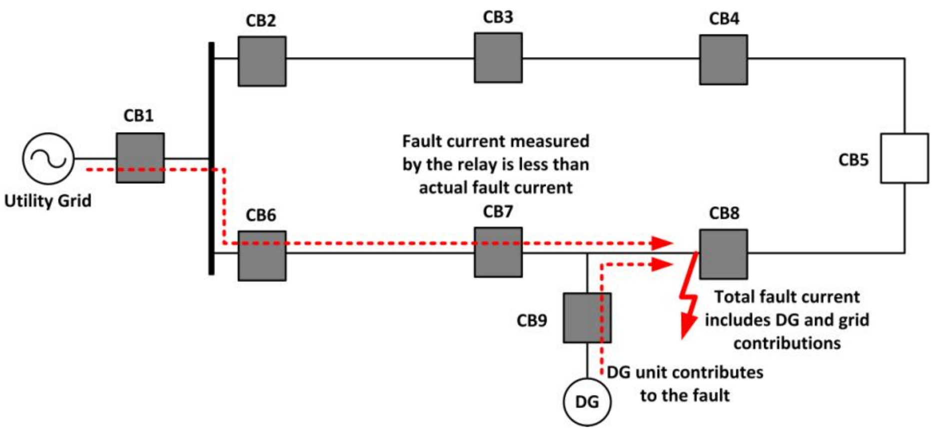
Protection must respond to both utility grid and microgrid faults
utility grid faults: protection isolates the microgrid from the utility grid as rapidly as necessary to protect the microgrid loads.
microgrid faults: protection isolates the smallest possible section of the feeder.

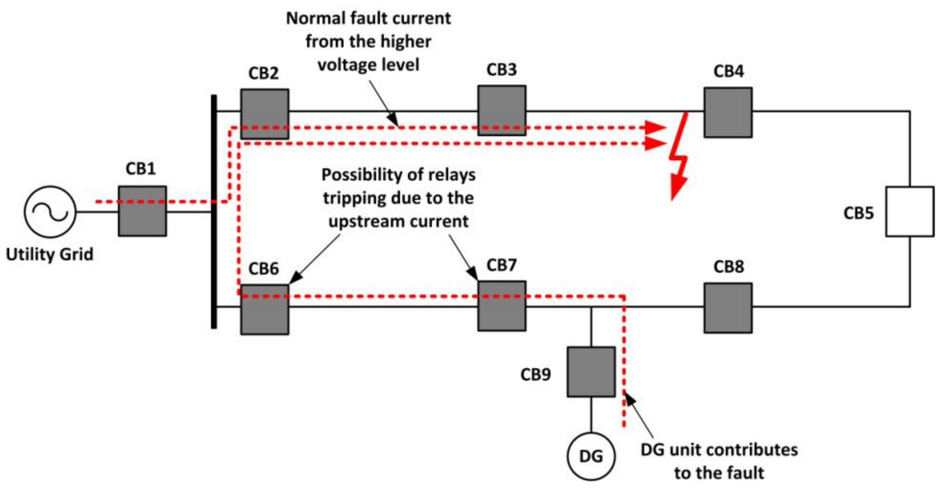
- After isolation from the utility grid local generators are the only fault current sources in the electric island
- Fault current level depends on type, size and location of DG but it is lower than the fault current from the utility grid

© ABB Group

Microgrid protection
Other key issues

- Changes in the magnitude and direction of short circuit currents (DER on/off, network configuration incl. islanding)
- Reduction of fault detection sensitivity and speed in tapped DER connections
- Unnecessary tripping of utility breaker for faults in adjacent lines due to fault contribution of the DER
- Auto-reclosing of the utility line breaker policies may fail





© ABB Group

Microgrid protection
Strategies

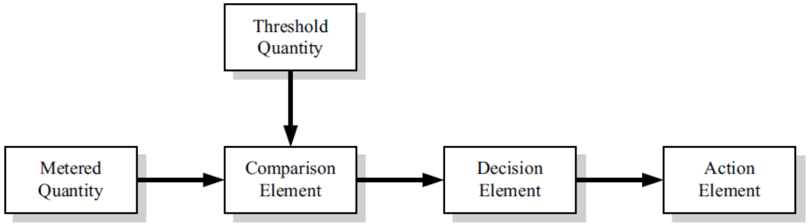
- Microgrid protection strategies ideally should be generic such that they could be:
  - applicable for both grid and islanded operation
  - adapted to any DER type and penetration level
  - scalable so that the strategy does not need to be redefined with each new DER connection
- May include requirements for:
  - dynamic protection settings management for protection coordination
  - modifying or replacing protection devices
  - use of advanced protection functions

© ABB Group

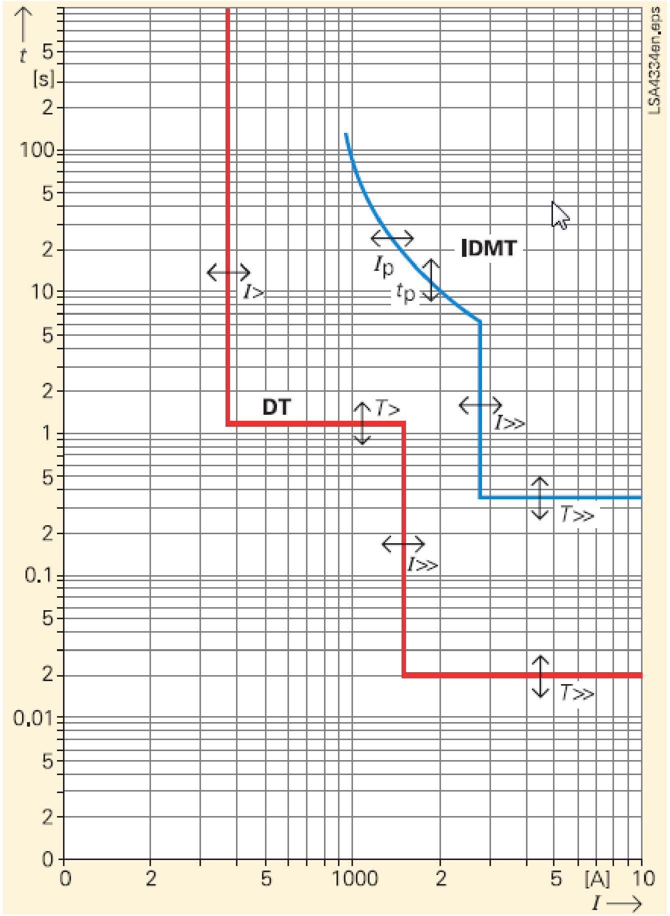
Protection settings
Overcurrent protection

U/O Voltage and U/O frequency protection usually have 1-2 steps (definite time and instantaneous)

- Measured values are compared with pre-calculated settings and relay generates a tripping command when the measured value exceeds the thresholds



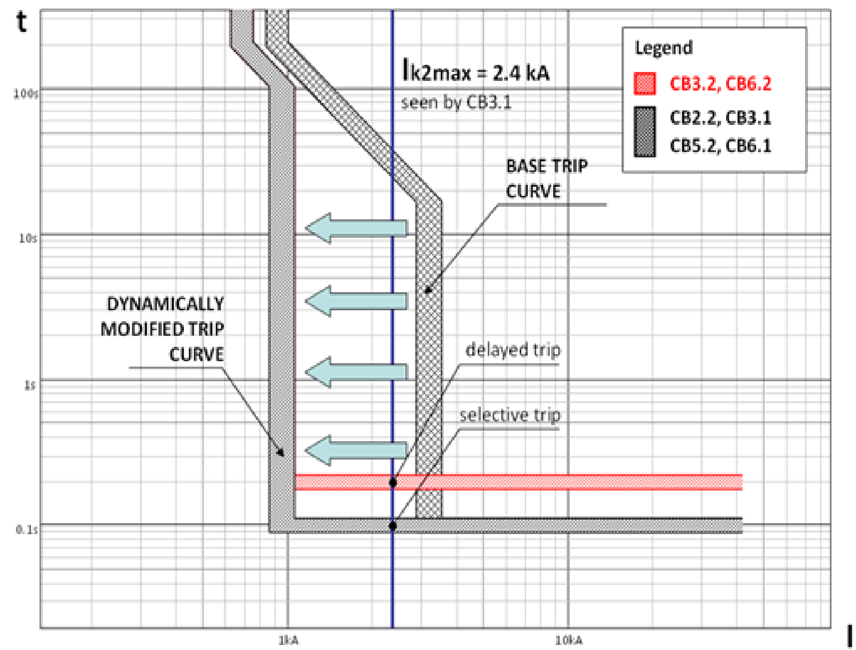
- Settings are usually calculated at the design stage and are not touched afterwards
- Calculations are done either manually or with software tools for complex grids based on standards, e.g. IEC60909, IEC60255
- Multiple setting groups possible today (switching by means of an external command) but not actively used



© ABB Group

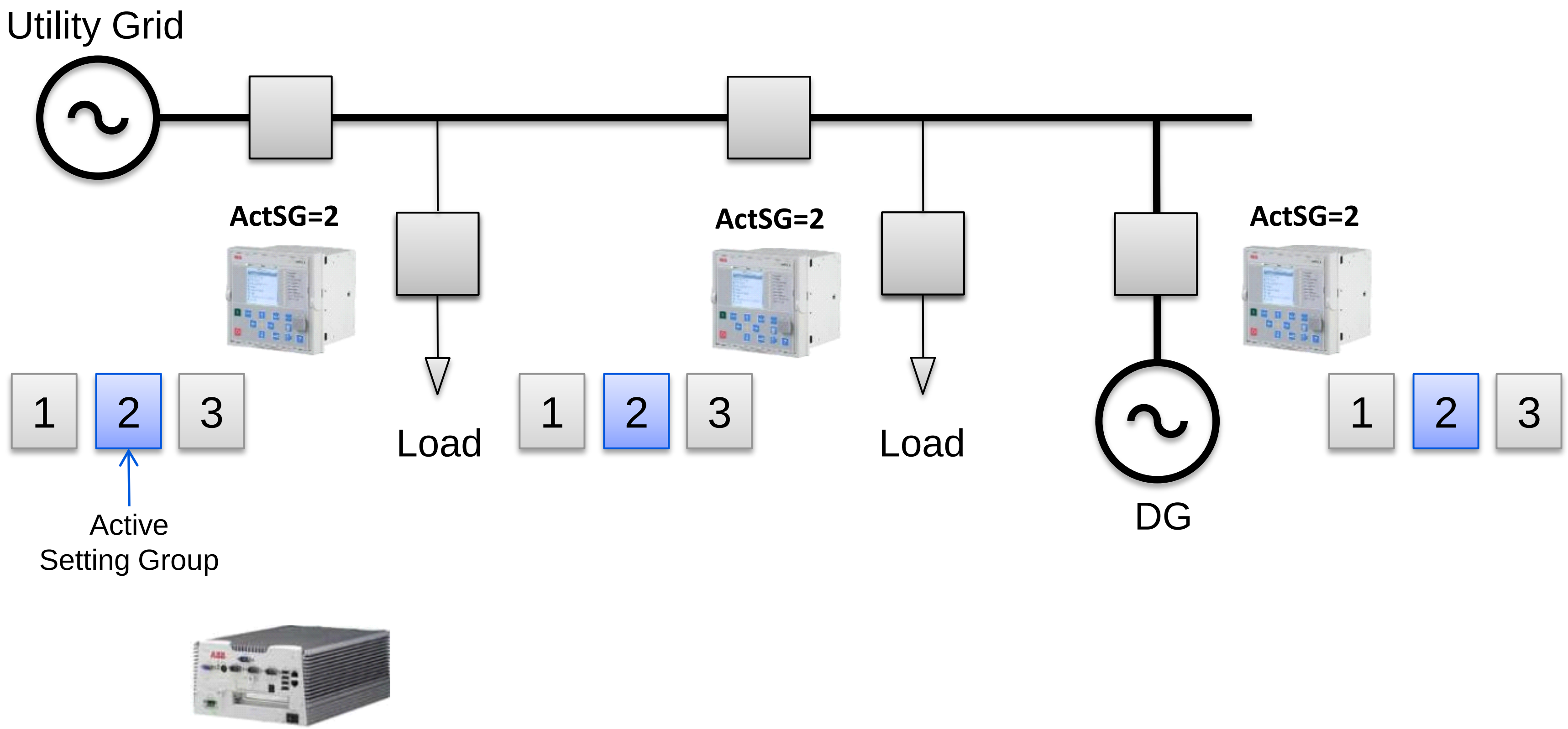
Microgrid protection
Adaptation of protection settings

- Adapt protection settings to the actual state of the microgrid (DER, feeder) based on the preset logic
- Accomplished by monitoring of actual protection settings and DER/network connectivity
- A programmable logic application is called to perform after changes in circuit breaker status
- Suggestions for practical implementation:
  - Use of IEDs with directional over-current protection function and with multiple setting groups
  - Use of communication infrastructure and standard protocols to exchange information between IEDs and a central setting coordination unit (e.g. substation computer or RTU)



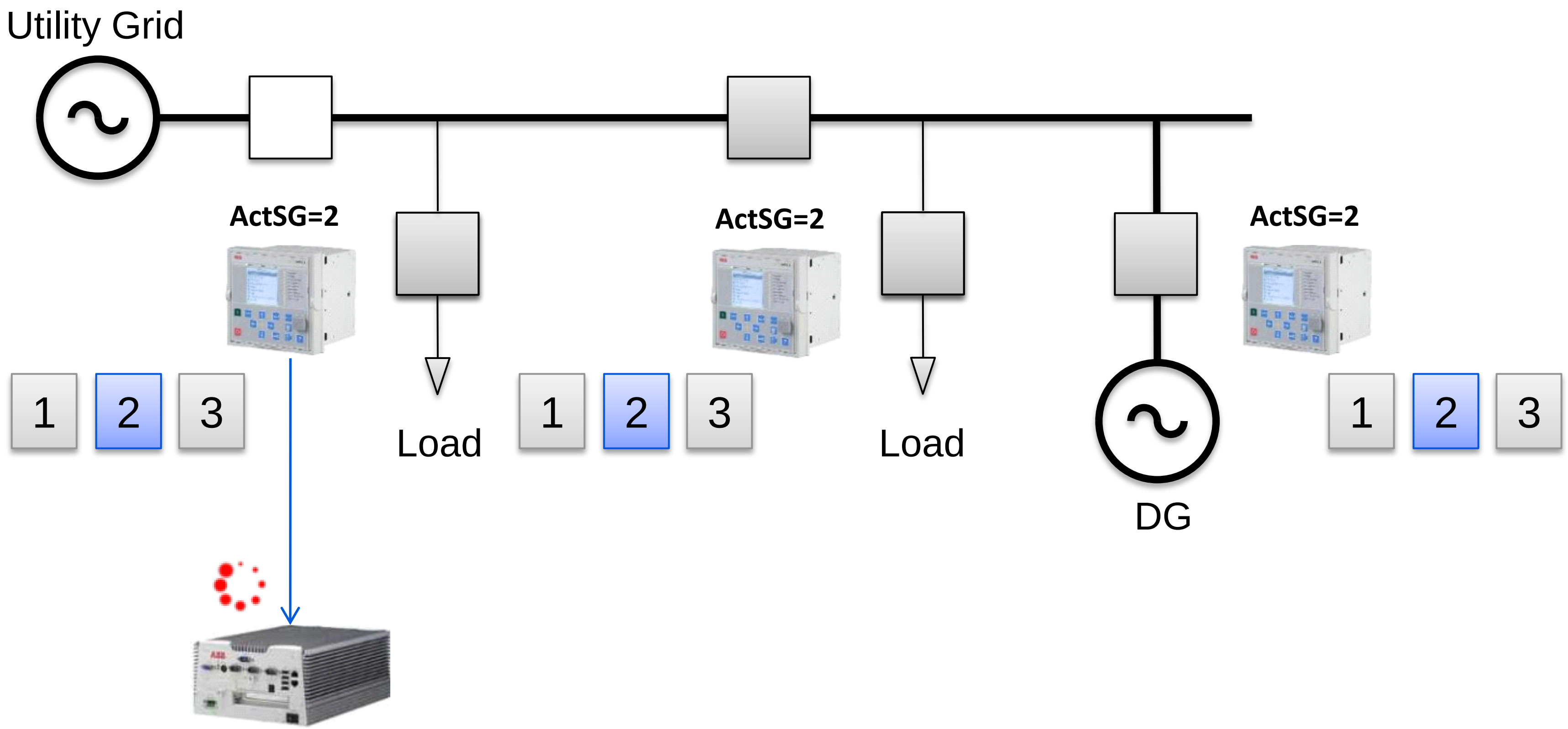
© ABB Group

Microgrid adaptive protection
Centralized adaptation scheme example



© ABB Group

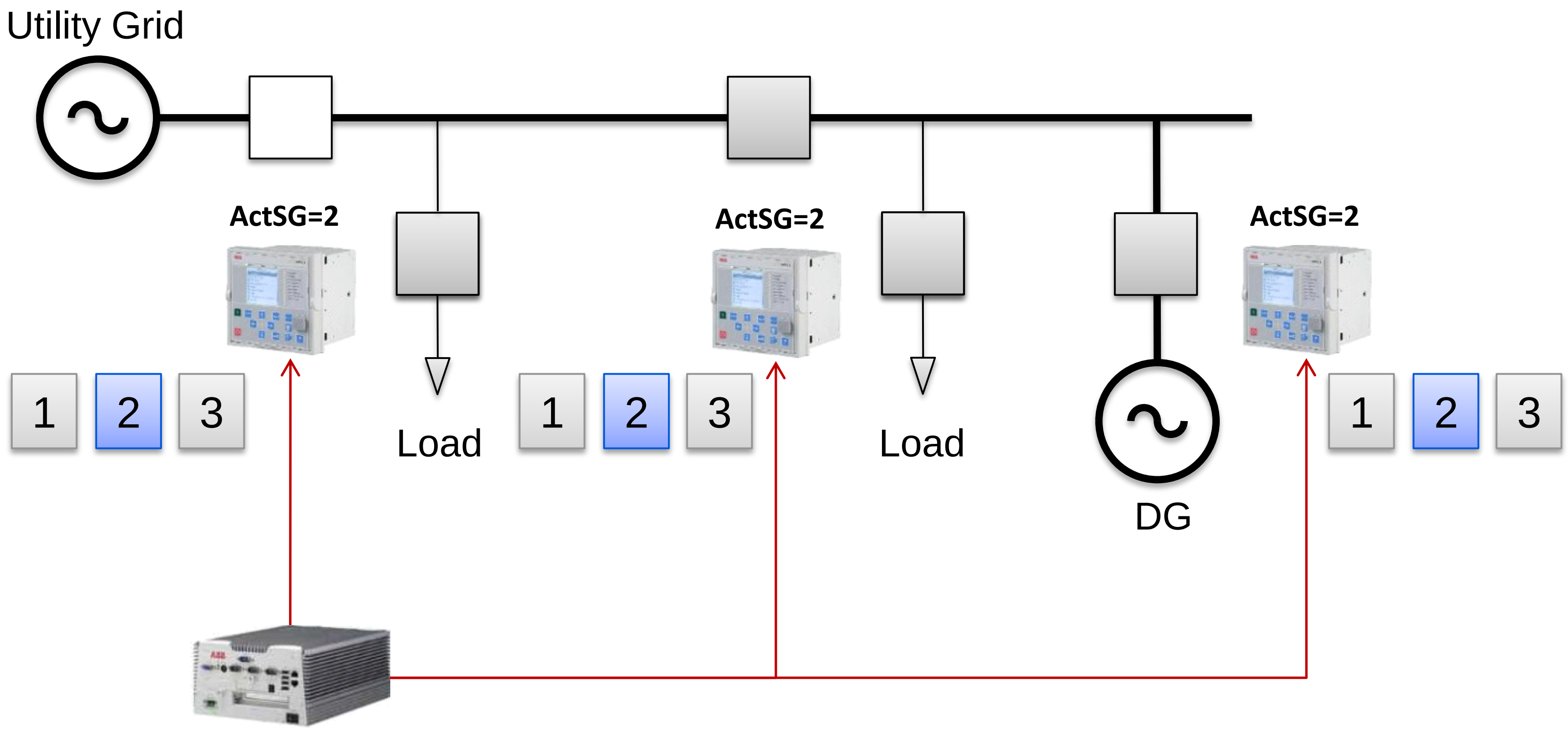
Microgrid adaptive protection
Centralized adaptation scheme example



1. Data (CB status) are transmitted from the end devices using unsolicited messages as conditions change. The central controller also polls each end device periodically to ensure that the end device is still healthy.
2. The central controller analyzes the network state and if necessary adapts protection settings to fit the new network configuration

© ABB Group

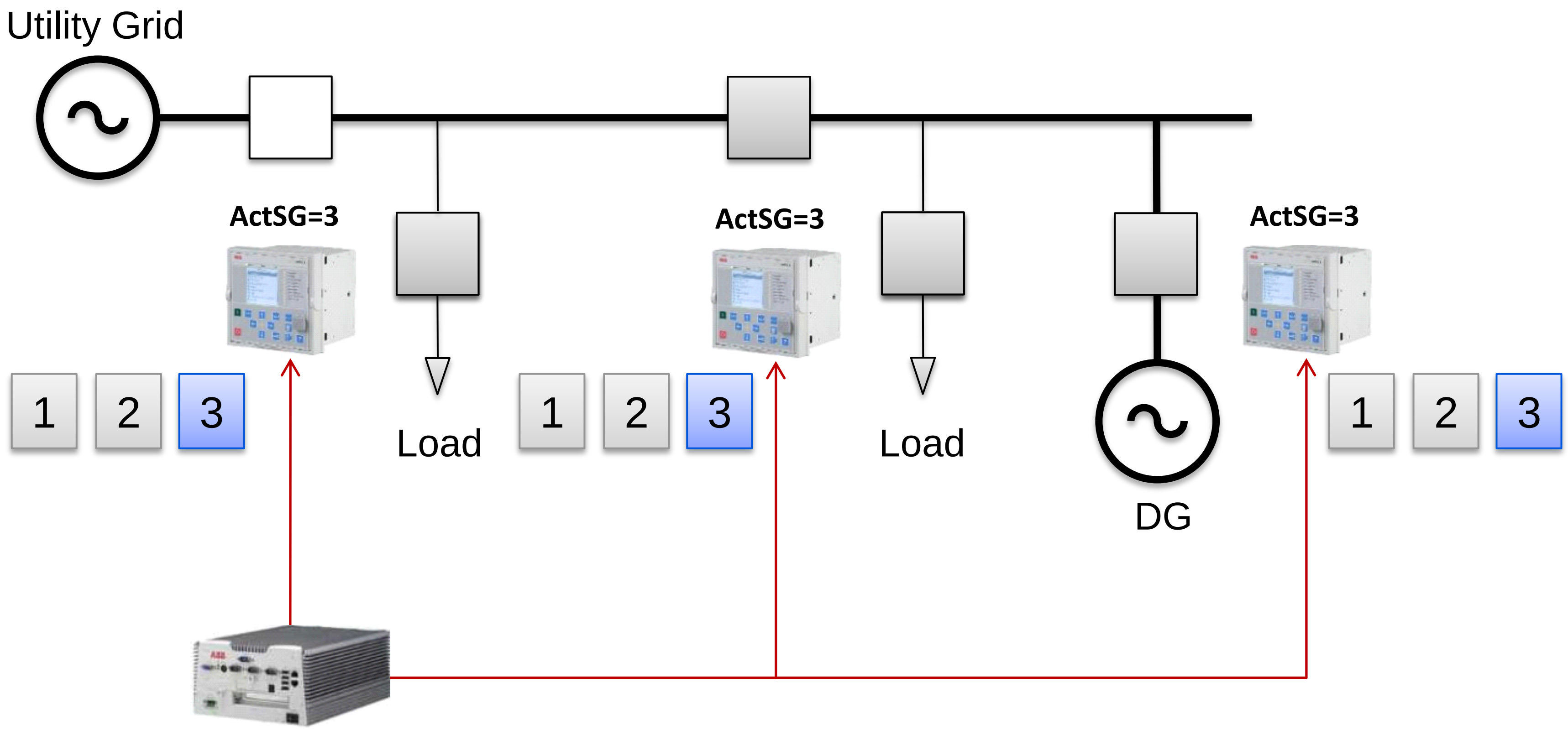
Microgrid adaptive protection
Centralized adaptation scheme example



1. Data (CB status) are transmitted from the end devices using unsolicited messages as conditions change. The central controller also polls each end device periodically to ensure that the end device is still healthy.
2. The central controller analyzes the network state and if necessary adapts protection settings to fit the new network configuration
3. The central controller sends control messages (to switch settings) to the field devices

© ABB Group

Microgrid adaptive protection
Centralized adaptation scheme example

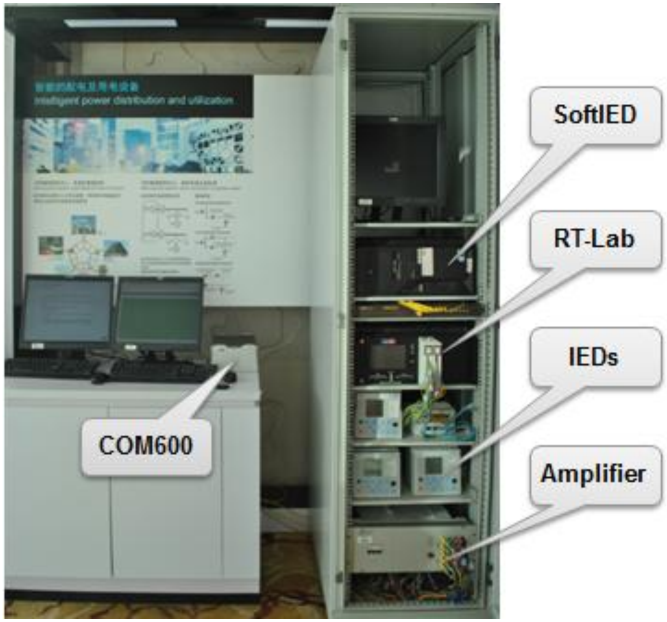


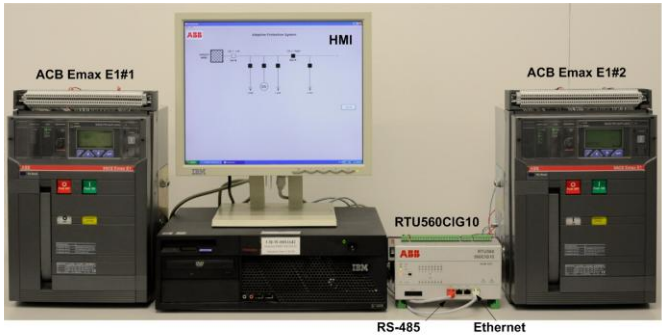
1. Data (CB status) are transmitted from the end devices using unsolicited messages as conditions change. The central controller also polls each end device periodically to ensure that the end device is still healthy.
2. The central controller analyzes the network state and if necessary adapts protection settings to fit the new network configuration
3. The central controller sends control messages (to switch settings) to the field devices

© ABB Group

Microgrid protection
Centralized adaptation scheme lab tests

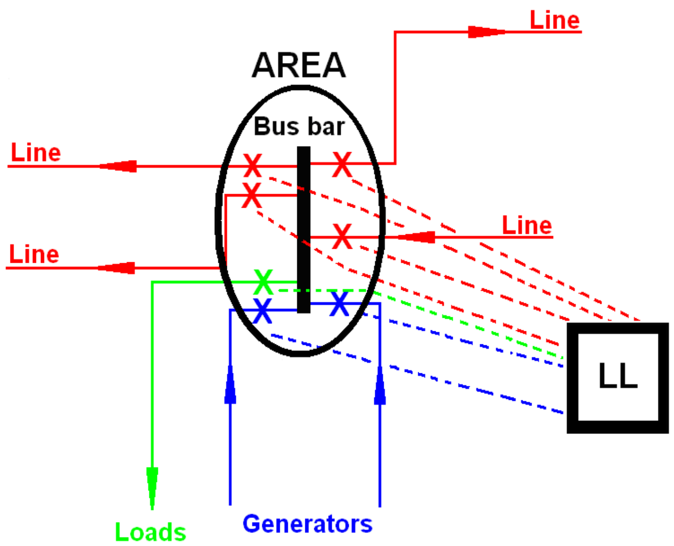
- Centralized approach has been tested in the lab (focus on data exchange) with a realization for MV (IEC61850) and LV (Modbus) grids
- In addition a real-time HIL simulations have been conducted
- Adaptation process is limited by communication system/protocol capability and takes <100 ms in MV and 700 ms (per circuit breaker) in LV
- The system demonstrated good performance and operated properly in different conditions (including situation when settings were forced manually to the wrong setting group)

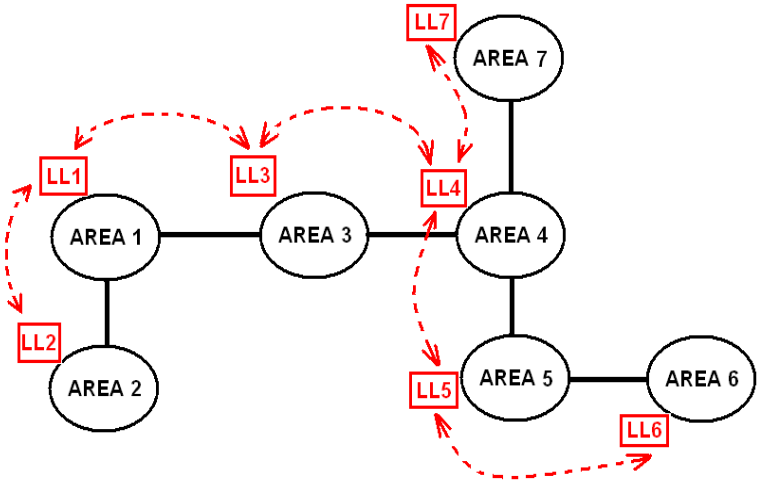




Microgrid adaptive protection
Decentralized adaptation scheme

- Aimed to simplify an implementation for a microgrid with a large number of circuit breakers
- Protected system is split into small areas being delimited by the adjacent switching devices coordinated by local units (LL)
- Each local unit communicates with units in directly adjacent areas and exchange information on local short circuit levels (SCL)

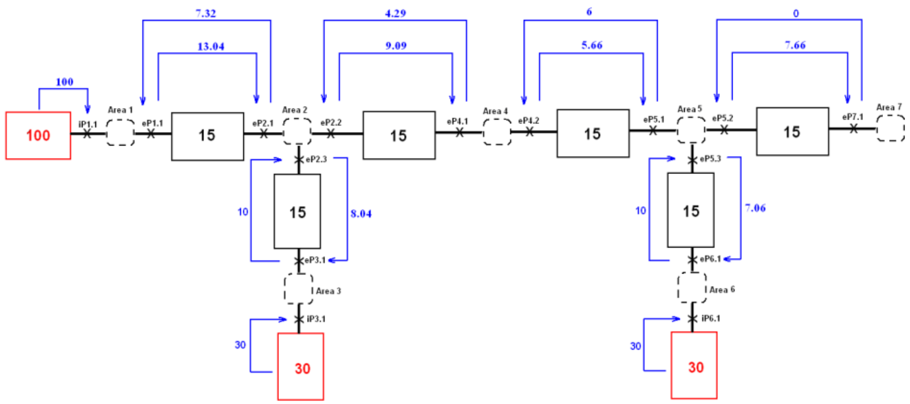


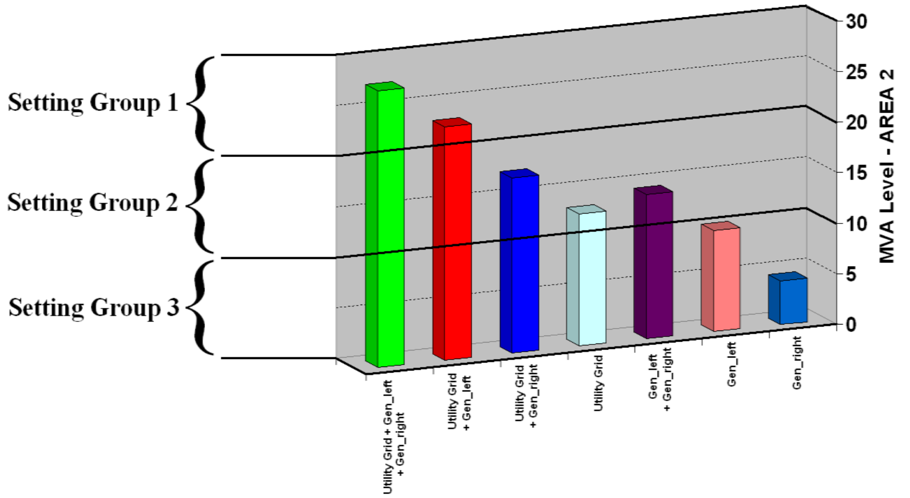


Microgrid adaptive protection
Decentralized adaptation scheme

MVA method: each network component is replaced by a block representing the contribution or the reduction of the SCL expressed in MVA

- Configuration change in an area triggers re-evaluating of a local SCL using the MVA method
- Each protection setting group corresponds to a specific range of available SCLs
- Local unit decides on switch/keep an active setting group
- SCL information is sent to neighbouring areas where it is further used to re-evaluate local SCLs
- The adaptation process progressively advances through the microgrid



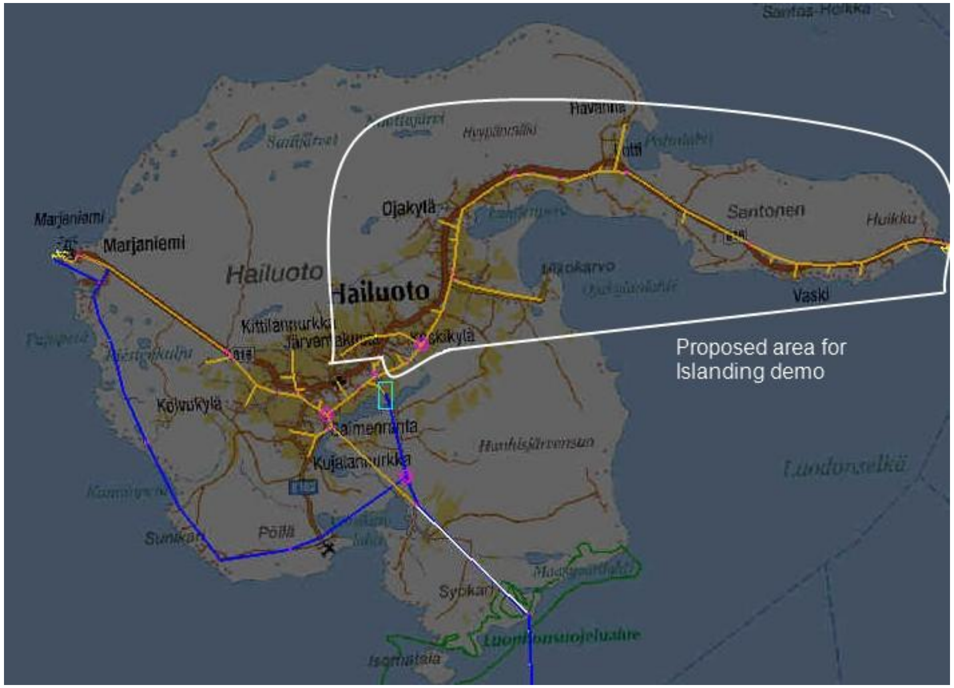


© ABB Group

Hailuoto microgrid
Practical demonstration of adaptive protection

Hailuoto is the largest island of Finland and the Northern Gulf of Bothnia in the Baltic Sea with 1000 regular inhabitants and 600 holiday houses.

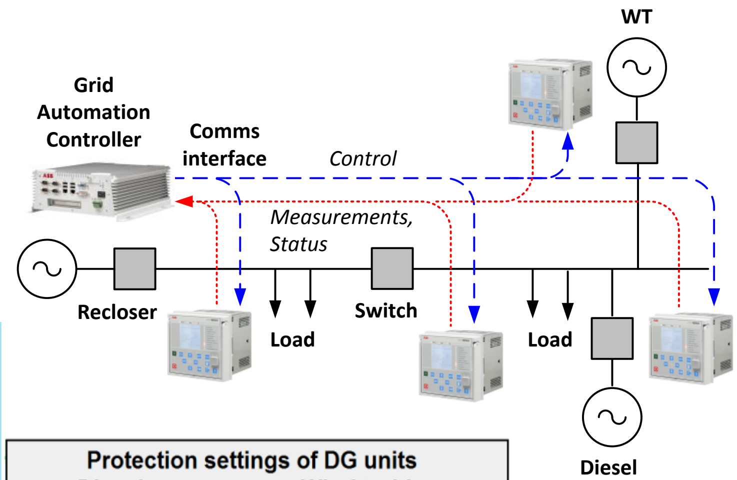
- Goal is to develop and demonstrate in the field a centralized protection coordination and active microgrid management
- Active management functionalities include:
  - Protection settings changing based on microgrid topology (e.g. grid connected ⇔ island)

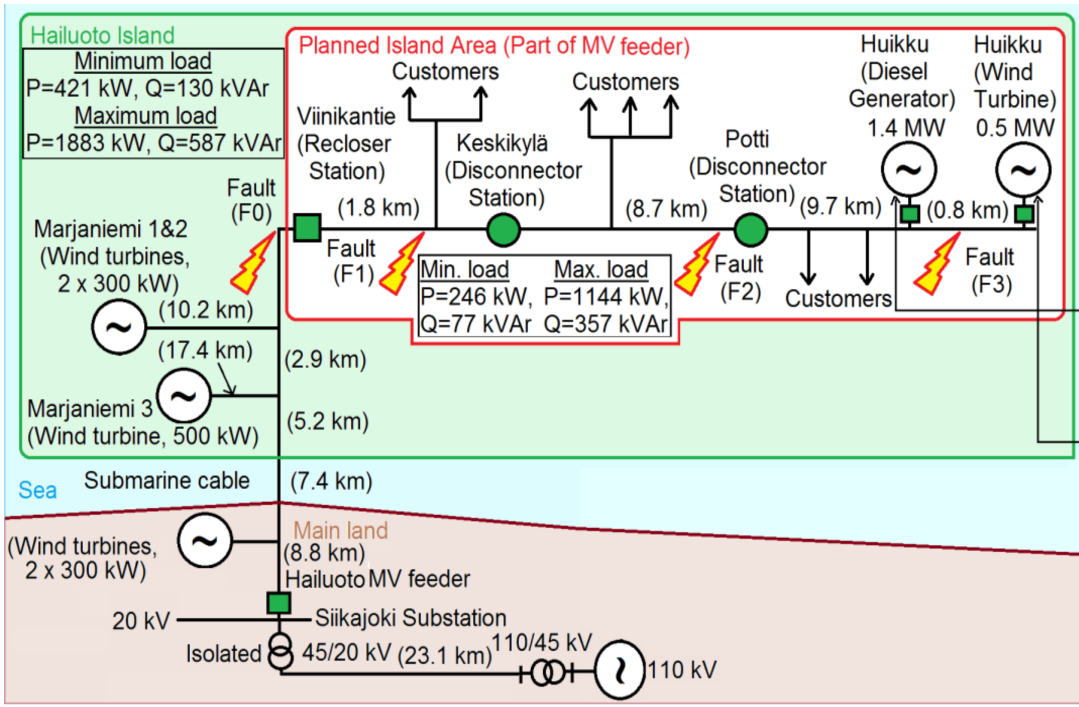


  - Transition between grid connected and islanded operation modes:
    - Unintentional islanding via black-start
    - Intentional islanding via SCADA
    - Re-synchronization to the utility grid

© ABB Group

Hailuoto microgrid
System configuration





Protection settings of DG units

Diesel	***Wind turbine***
Frequency f > 54 Hz, 1.3 s f < 47 Hz, 2.9 s	Frequency f > 51.5 Hz, 0.2 s f < 48.5 Hz, 0.2 s
Voltage U > 1.1 pu, 2.7 s U < 0.85 pu, 2.5 s	Voltage U >> 1.1 pu, 0.05 s U > 1.085 pu, 60 s U << 0.5 pu, 0.1 s U < 0.855 pu, 10 s
Underpower P < 130 kW, 12 s	Over-current (LV side currents) I >> 3150 A, 0.1 s I > 550 A, 0.6 s

Fault analysis simulations used to determine optimal settings and different operation sequences

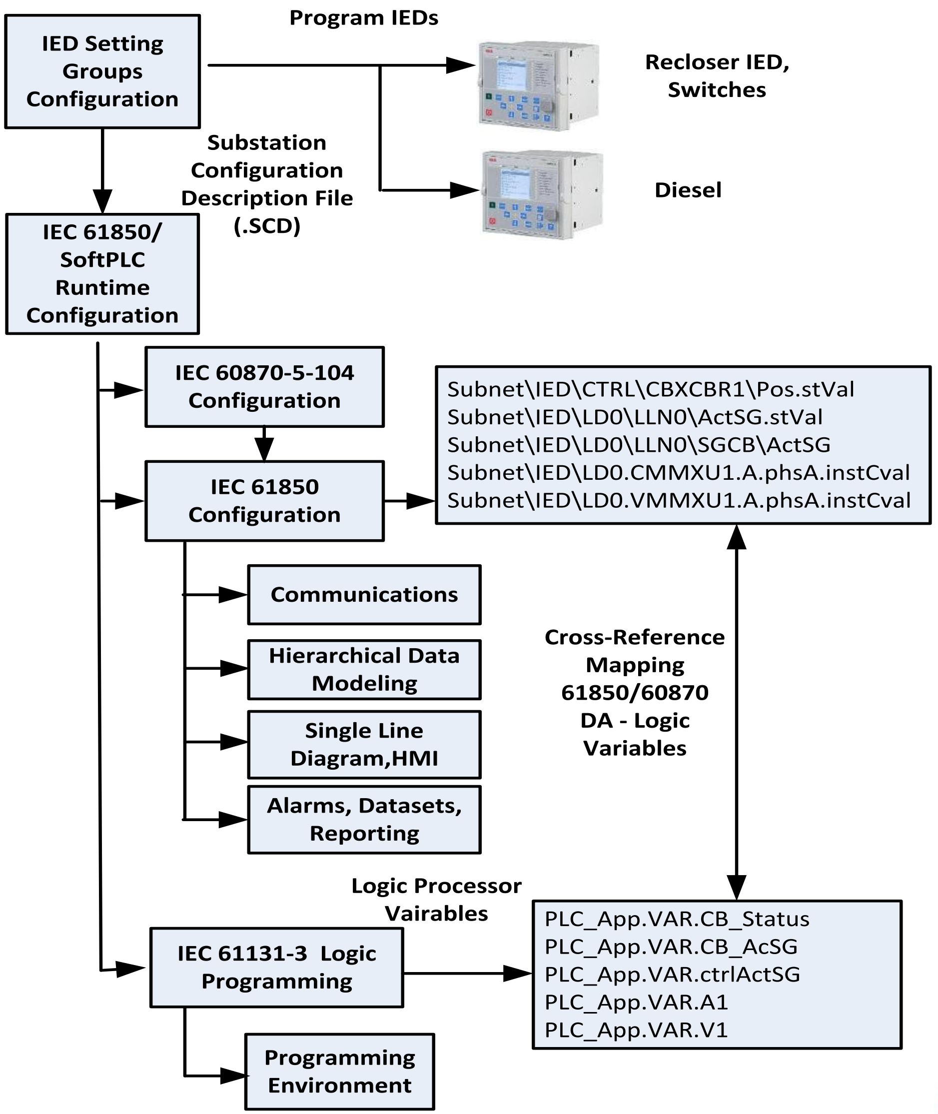
- Grid connected no DG
- Grid connected with DG
- SCADA command (intentional islanding)
- Black-start (unintentional islanding)
- Islanded operation

} active setting group indicates to the operator actual microgrid configuration

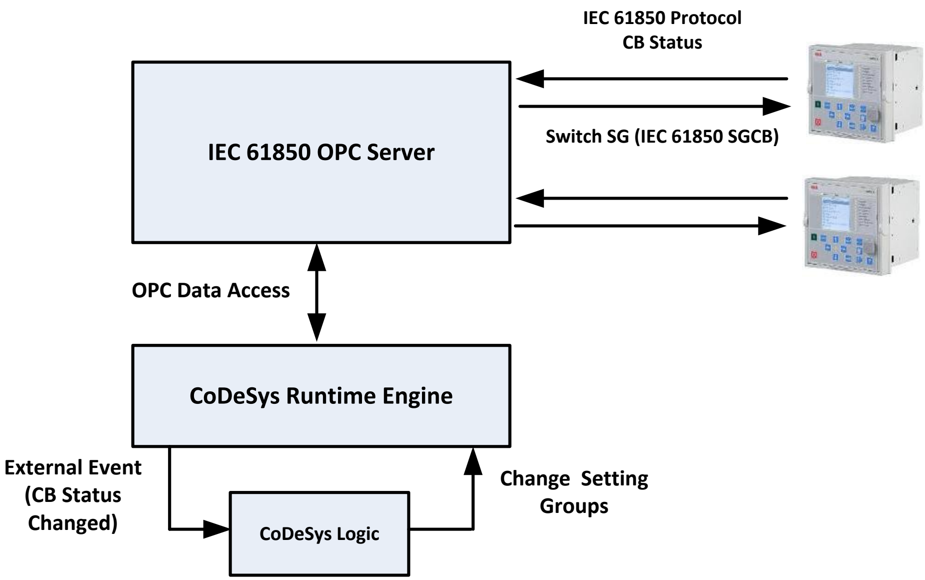
© ABB Group

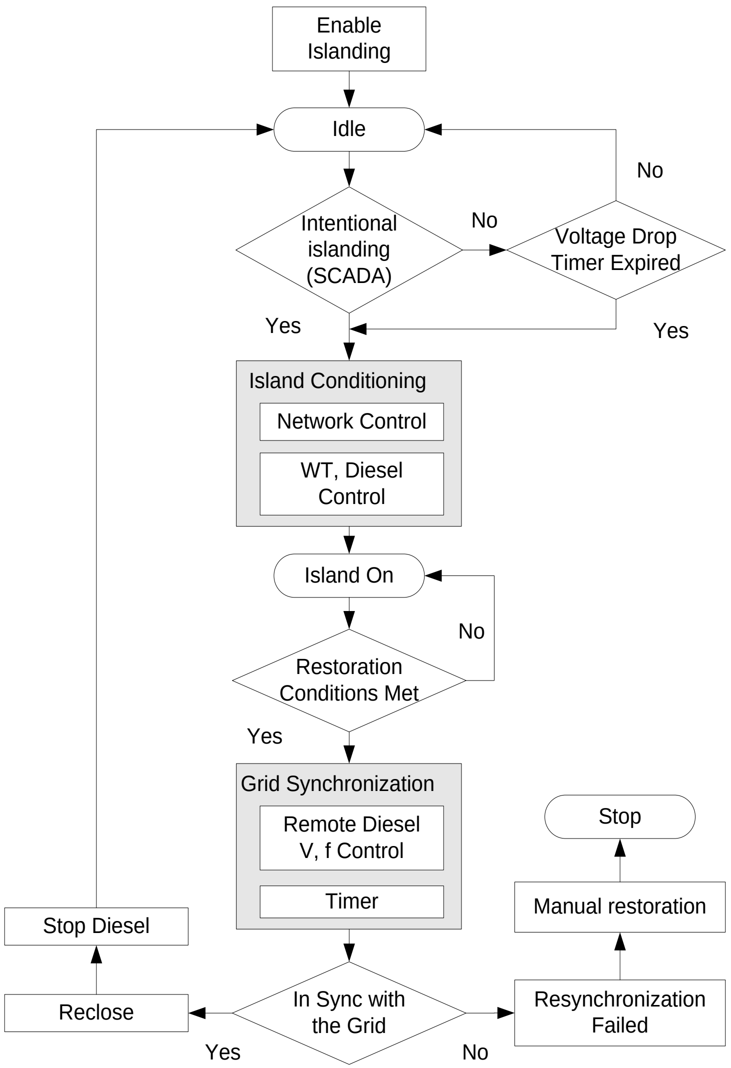
Hailuoto microgrid
Automation system configuration

- Off-line process
- “Trusted” settings are uploaded to IEDs as multiple setting groups
- IEC 61850 is used as a master protocol for communications with the IEDs
- A standard IEC 61131 programming languages are used in the PLC application which allows easy cross-platform transfer of the application



Hailuoto microgrid
On line operation and control logic





- OPC Data Access mechanism provides a way to supply the IED data received from the field devices to the IEC 61131 Logic Processor
- OPC Client/Server architecture allows feeding the control actions back to the IEDs
- Additional OPC server instance can be used to map and broadcast the IED data upstream to the distribution network control center via SCADA

Microgrid Protection
Key take away points

- High penetration level of DER and islanded operation mode pose main protection challenges in microgrids
- Ideally protection system must follow microgrid configuration changes
- At the moment it looks like switching between the pre-calculated "trusted" setting groups is a preferred solution
- Centralized adaptive protection system based on full connectivity model can be suitable for small scale microgrids
- This solution is currently in the pilot phase in Hailuoto microgrid
- Large scale microgrids may require a hierarchical scheme with limited connectivity model
- Adaptive protection may increase availability of local generation and reduces outage time for the customers without a need to change existing hardware

© ABB Group

Microgrid Protection
Further reading

- A. Oudalov, A. Fidigatti, “Adaptive Network Protection in Microgrids”, International Journal of Distributed Energy Resources, Vol.5, No.3, pp.201-226, July-September 2009
- W. Zhao, A. Oudalov, B. Su, Y. Chen, “Research on Close-Loop Simulation for Centralized Coordination of Protection Settings”, in Proc. of China International Conference on Electricity Distribution, Shanghai, 2012
- A. Oudalov, L. Milani, E. Ragaini, A. Fidigatti, “Sample Implementation of Adaptive Protection for Low Voltage Networks”, PAC World Magazine, Vol.20, pp.28-33, June 2012
- D. Ishchenko, A. Oudalov and J. Stoupis, "Protection Coordination in Active Distribution Grids with IEC 61850," in Proc. of IEEE T&D conference, 2012, Orlando, FL, USA.
- H. Laaksonen, D. Ishchenko, A. Oudalov, “Adaptive Protection and Microgrid Control Design for Hailuoto island”, currently under review in IEEE Trans on Smart Grids.

Power and productivity
for a better world™