Distributed and hierarchical congestion management in distribution networks containing distributed energy resources

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IDE4L is a project co-funded by the European Commission (Project no: 608860)
• Active Network Management concept
• Distributed automation system
• Congestion management concept
• Demonstrations
• Conclusions
The Project at a glance

- FP7 demonstration project (9/2013 – 10/2016)

- Scope: Active distribution network management
  - From the planning to the real-time operation
  - From the MV up to LV single customer
  - DSO interaction with TSO, DER, μGrid and Aggregator
Breakthroughs

WP7 Demonstrations

**WP2** Planning tools for distribution network management
- ANM concept
- Target and expansion planning including ANM
- Operational planning including DER uncertainty

**WP3** Distribution network automation architecture
- Automation concept
- Smart meter as a sensor
- Testing Platform for monitoring & control systems
- Hierarchical and decentralized automation

**WP4** Fault location, isolation and supply restoration
- Decentralized FLISR
- IEC 61850 Distribution Protection System Reconfiguration
- Microgrid interconnection switch

**WP5** Congestion management
- Decentralized state estimation and state forecast
- Tertiary control – Network reconfiguration
- Secondary control – Coordination of voltage controllers
- Dynamic tariff

**WP6** Distribution networks dynamics
- Aggregator concept
- Optimal scheduling of flexibility
- Transmitting synchro-phasors & real-time model syntheses
- Improved microgrid operation

**WP7** Demonstrations
- IEC4L.EU – ISGT Europe 2016 tutorial October 9th 2016
- Concept
- Monitoring
- Control
- Market
Vision of future smart grid

- Ideal grid for all
- Microgrids
- Energy communities
- Grid infrastructure
- Renewable energy resources
- Market design
- Smart charging of EV
- Smart homes and PV
- System management and design
- Controllable loads and energy efficiency
- Aggregator
- Storage
- Power to gas
- Advanced monitoring
- Distribution automation
- Balancing
Policies of electricity network

- Today networks are always **over-dimensioned** due to quality of supply obligations and missing possibility to control DERs
- Some companies are already forced to utilize **production curtailment** to manage their networks
- In future **more flexibility** is needed to integrate more RES and DERs in power system
  - Controllability of distribution network via advanced ICT
  - Decentralization of network management due to scale of the system
Active distribution network

• Active distribution network utilize DERs in grid management → Active Network Management (ANM)
• DERs are integrated as part of grid and markets instead of ”fit and forget” connection
• ANM should provide synergy benefits for DSO and customers
IDE4L automation architecture
Roles of grid operators and aggregator

1. DSO/TSO
   - Validates the submitted offers:
     - Off-line validation
     - Real-Time validation
   - Purchases flexibility services for avoiding network constraints
   - Calculates and provides the Flexibility Table (Limits for each Load Area)

2. Aggregator
   - Forecasting of consumption, production, price, etc.
   - Flexibility estimation of customers
   - Determination of market bids
   - Commercial optimal planning
     - Maximization of aggregator profit
Monitoring, protection and control system

- Complete network will be monitored and controlled
  - Intelligent Electronic Devices (IEDs)
  - Coordination and merging of information and decisions at substations

- DA applies variety of communication technologies
  - Primary substations - SCADA and possibly other IT systems (fibre optics, wireless)
  - Secondary substations and MV switching stations (wireless)
  - Smart meters (PLC or wireless)

- Ethernet is becoming the prevalent communication standard for all automation devices
  - IEC 61850 GOOSE and MMS
  - DLMS/COSEM
  - IEC 60870-5-104
  - Modbus/TCP over LAN/WAN
Control of DERs from DSO’s viewpoint

• Regulation
  • Connection requirements → technical capabilities for the control of DERs
  • Dynamic tariffs to incentivize load shifting
    • Retail → off-peak day-ahead prices
    • Grid → off-peak network load

• Direct control
  • DSO’s own resources (OLTC, Reactive power compensation and FACTS)
  • Contracted non-market based control, e.g. voltage control of DG units
    • Emergency control to act just before protection

• Flexibility services from Commercial Aggregator
  • Scheduled re-profiling of flexible DERs
  • Conditional re-profiling of flexible DERs
Active network planning

• **Active network becomes alternative for network reinforcement**
  - Postponing investments of physical infrastructure by ANM
  - Replacing network reinforcement with smart functionalities

• **Traditionally worst case design principle**
  - Firm connection capacity always available for all customers
  - DG impact $\rightarrow$ maximum production – minimum loading condition
  - Leads to over-dimensioning of network and the evaluation of smart functionalities is limited to peak conditions

• **Stochastic planning of active network**
  - Non-firm connection (based on dedicated contract) increase network hosting capacity remarkably
  - Enable full utilization of ANM
• Active Network Management concept
• Distributed automation system
• Congestion management concept
• Demonstrations
• Conclusions
General architecture
Motivation

• Background
  • Little monitoring penetration in the distribution grid:
    • primary substations
    • secondary substation remote control
    • average values only
  • Electronic meters deployment mainly for billing and CRM

• Needs to be developed
  ★ LV grid: EV, PV, HP and demand-response schemes mainly affect the LV grid
  ★ Secondary substations: Improve the monitoring, protection and control of secondary substations
  ★ TSO-DSO: Need of dynamic information from DSO grid
Pillars

• **Amount of data increases**
  - 10 of PSs -> $10^6$ customers
  - averages only -> high-frequency measurements

• **Decentralized approach**
  - Data is collected/processed locally (LV data -> in SS; MV data -> in PS)
  - Only summary/alarms are reported to upper levels

• **Benefit: impact on CAPEX (scalability / modularity)**
  - Less-demanding communication is required
  - Faster response
  - reuse of existing automation components
Pillars

- The number/type of monitoring devices are increasing
  - Smart meters
  - Fault detectors / protections
  - Power quality meters / PMU
- Standards are needed to:
  - Limit the integration time
  - Limit the maintenance time
- Main standards:
  - CIM for grid assets
  - 61850 for data about the grid
  - DLMS/COSEM for metering data
- Benefit: Positive impact on CAPEX and OPEX (interoperability)
Commercial aggregator market setup

- **TSO**
  - Flexibility activation requests
  - Market clearing
  - Flexibility procurement

- **Flexibility market**
  - Sale bids
  - Flexibility activation requests
  - Flexibility validation
  - TSO/DSO coordination

- **DSOs**
  - Market clearing
  - Flexibility procurement

- **Commercial Aggregators**
  - Market clearing
  - Market clearing
  - Flexibility activation requests

- **Wholesale Market**
  - Market clearing
  - Purchase/Sale bids
  - Flexibility activation requests

- **Other market participants**
  - Market clearing
  - Purchase/Sale bids

- **Consumers Prosumers**
  - Market clearing
  - Flexibility activation requests

- **Market clearing**
  - Bilateral contracts
  - TSO coordination
Market operator (MO) as neutral market facilitator

Diagram showing interactions between Market Operator (MO), TSO, DSO, and other market participants like Producers, Retailers, CA 1, CA 2, CA 3, and BRP.
Flexibility products

Two types of standardized Flexibility Products

<table>
<thead>
<tr>
<th>AD Product</th>
<th>Conditionality</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scheduled re-profiling (SRP)</td>
<td>Unconditional (obligation)</td>
<td>The aggregator has the obligation to provide flexibility services</td>
</tr>
<tr>
<td>Conditional re-profiling (CRP)</td>
<td>Conditional (real option)</td>
<td>The aggregator must have the capacity to provide flexibility services</td>
</tr>
</tbody>
</table>
Aggregator’s real time algorithm

1: Order of flexibility activation
2: Status request (baseline + available flexibility) and operational status return
3: Allocation of flexibility volume among DERs proportional to their available amounts
4: DERs’ activation
5: Activation confirmation
6: Energy measurements (request and return)
7: Modification of flexibility volume target for remaining activation period and re-allocation of set points among DERs
8: Sending of modified control set points
Comparison of architectures

**Distributed / Decentralized**
- Local challenges
- Small-scale resources
- Scales well to whole system
- Less dependent on communication
- Needs to be coordinated with centralized systems
- Supports novel ideas: active networks and microgrids
- Information exchange is the key question for successful implementations

**Centralized**
- Global challenges
- Large-scale resources
- Scalability is an issue
- Very dependent on communication
- Does not necessarily require existence of distributed ach.
- Less flexible for novelties
- Software integration and communication QoS are the key questions
Substation Automation Unit (SAU)
Use cases

1. Monitoring
   - Real-time monitoring
   - Load and production forecasting
   - State estimation and forecasting
   - Dynamics of distribution grid

2. Protection
   - Logic selectivity
   - FLISR with DERs and μGrid

3. Control
   - Congestion management
   - Optimal scheduling
   - μGrid voltage control
   - Dynamic grid tariff
Substation Automation Unit

Control Center - DMS
Substations - IEDs
Prosumers – Smart meters and DER IEDs

SAU
Interfaces
Database
Applications
DLMS/
COSEM
MMS
Prosumers – Smart
meters and DER IEDs

Data
Acquisition
State
Estimation
Forecast
Power
control

Reports

Management
model
CIM
Bridge
model
IEC 61850

Power control
State Estimation
Data Acquisition
Reports

Control Center - DMS
Substations - IEDs
Prosumers – Smart meters and DER IEDs
Demonstrations

Testing phase: a three-step procedure

Building-blocks, e.g.:
1. Algorithms
2. Protection devices
3. Third party devices
4. Third party software

Groups of building-blocks, e.g.:
1. State estimation algorithm within a PC connected to an RTU via a 61850 interface

Use cases, e.g.:
1. Monitoring of LV grid (PC + state estimation + RTU + Smart meters + interfaces)

1st Dev. lab
2nd Integration. lab
3rd Demo
Unareti Demo Site Overall Architecture
LV Network Demonstrator

Active Power of 4 PV Units (Solar Eclipse, 20 March 2015)
Net load forecast of prosumers

Ostkraft

Fenosa, producer

Unareti
State estimation

Secondary substation total load (kW) on 2016-08-30

Ostkraft

RMSE as a function of time and electrical distance (Z) from Unareti
Design and implementation of SAU
1. Use Cases

2. SGAM Architecture

3. Implementation of architecture

4. Architecture evaluation
1. Use Cases

- State estimation, forecast, network update, measurement collection
- LV, MV, control center power control, block OLTCs, FLISR
- Purchase of energy and flexibility, activation of flexibility
1. Use Cases
Use Case description - example

<table>
<thead>
<tr>
<th>Steps</th>
<th>Information producer</th>
<th>Information receiver</th>
<th>Function</th>
<th>Information exchanged</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SAU(PSAU).MMS</td>
<td>SAU(SSAU).MMS</td>
<td>Data Report</td>
<td>Switch Status</td>
<td>TT = 100 ms ...</td>
</tr>
<tr>
<td>2</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td></td>
</tr>
</tbody>
</table>

Actors
SAU(PSAU).MMS
SAU(PSAU).RDBM
SSAU(PSAU).IEC104
DMS.MMS
Sensor
SAU(SSAU).MMS
DMS.Modbus
SAU(PSAU).Functions
SAU(PSAU).Modbus
DMS.IEC104
IED(PSIED).MMS
IED(PSIED).functions

Functions
Data acquisition
Data report
Data storage
Signals sampling
Statistical calculation

Information exchanged
Switch status
Voltage measurement
Current measurement
Power/energy measurement

Requirements
Requirement: transfer time
Requirement: Transfer rate
Requirement: Synchronization
Requirement: Availability
2. SGAM architecture
General description and link to use cases

1. Business framework
2. Functions to be implemented
3. Data models in the main automation standards
4. Communication protocols
5. Components, both hardware and software to take part to the automation system
2. SGAM architecture
Business layer and mapping to component layer

Business layer
- Business actors are connected by business transaction
- Each one has a business goal
- Business actors are mapped onto components

Business goals
- Optimize energy costs of portfolio
- Sell services as price, weather, generation forecasts
- Ensure market settlement
- Monitor of grid status, power quality and security requirements
- Maximize income from energy selling and purchase
2. SGAM architecture
Component layer

Each Automation actor is defined in terms of
- Interfaces
- Database
- Functions

New automation actors developed:
- Substation Automation Unit
- Further development for
  - Commercial aggregator
  - Distribution management system (DMS)
  - MicroGrid Central Controller

Also present in function layer and UCs
2. SGAM architecture

Function layer

Functions are mapped to
- Actors
- Use cases
- Zones and domains of Smart Grid Plane

Function list

- Bid acceptance/modification
- Bid submission
- Check flag
- CIM parsing
- Commercial optimal planning
- CRP activation request
- CRP Validation request
- Data acquisition
- Data Curation and Fusion
- Data reconstruction
- Data report
- Data storage
- Detect error
- Dynamic info derivation
- Fault detection
- Fault isolation
- Load area configuration
- Load forecast
- Market clearance
- Market infos
- Missing data
- Non-convergence detection
- open/close switch
- Optimal power flow
- power flow
- power quality control
- power quality indexes
- Protection update
- algorithm performance index
- Reading/Writing IEDs setting
- Second fault isolation
- Signals sampling
- State estimation
- State forecast
- Statistical calculation
- synchronization
- Validation reply
- Validation request

Control Center

Power Control

MV Power Control

MV State Estimation

LV real time Monitoring

MV real time Monitoring

SAU

DMS

MGCC

IED
2. SGAM architecture
Information layer

IEC 61850 – data models

<table>
<thead>
<tr>
<th>Logical node</th>
<th>Data object</th>
<th>Data Attribute</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATCC</td>
<td>BndCtr</td>
<td>ASG setMag</td>
</tr>
</tbody>
</table>

CIM – data models
2. SGAM architecture
Communication layer

<table>
<thead>
<tr>
<th>Steps</th>
<th>Information producer</th>
<th>Information receiver</th>
<th>Function</th>
<th>Information exchanged</th>
<th>Requirement</th>
</tr>
</thead>
</table>
| 1     | SAU(PSAU). MMS      | SAU(SSAU). MMS      | Data Report | Switch Status        | Transfer Time = 500 ms  
Transfer Rate = 1000 kb/s  
Synchronization accuracy = ...  
Availability = ... |
| 2     | ...                  | ...                  | ...       | ...                   |             |

Diagram:
- Service Provider Platform (SPP)
- Market Operator Platform (MOP)
- Commercial aggregator automation system (CAAS)
- Distribution Management System (DMS)
- Transmission System Operator Energy Management System (TSOEMS)
- Substation Automation Unit (SAU)
- MicroGrid Central Controller (MGCC)
- Intelligent Electronic Device (IED)
2. SGAM architecture
One step toward implementation

Function layer
- Functions have been realized in WP4 (FLISR), WP5 (Monitoring and LV, MV, control center control), WP6 (business and commercial aggregator)
- Functions are adapted in order to read and write from a standardized IDE4L database

Information layer
Exchanged data are clustered onto classes and mapped to
- CIM data models for static data and business related data
- 61850 for real time data

Communication layer
- The requirements of the information exchange grouped onto technology classes

Component layer
Each component is implemented as
- Software/Hardware interfaces
- Database
- Functions

Smart Grid Coordination Group, CEN-CENELEC-ETSI, Tech. Rep., 2012
3. Implementation of architecture
Database structure

**Measure & Command Model**
- Physical devices, logical devices, logical nodes, data objects and data attributes with real time data
- Set of information to parameterize the communications interface to each physical device (such as IP addresses, TCP ports, users and passwords, etc.)

**Network Model**
- Network topology and parameters of lines, customers and generators

**Management Model**
- Represents the models related to an algorithm.
- Instantiate, parameterize and control the execution of a specific algorithm

**Bridge Model**
It is the connection schema for all other schemas.
- Relations among Measure & Control real time quantities with the network topology
Conclusions and Exploitation of IDE4L architecture

1. Use cases
   - 29 use case detailed descriptions (11 monitoring, 11 control, 7 business)
   - List with description of actors, information exchange, functions and communication requirements

2. SGAM architecture
   - SGAM communication, information, component, business detailed SGAM layers in .xls and enterprise architect files

3. Architecture Implementation
   - 61850, CIM information mapping for whole set of information exchanges in UCs in .xls tables to facilitate standard implementation of architecture
   - Database structure and sample communication interfaces

4. Evaluation of architectures
   - Architecture metrics definition and results
• Active Network Management concept

• Distributed automation system

• Congestion management concept

• Demonstrations

• Conclusions
Why congestion management?

Voltage profiles without generation

- MV feeder voltage drop
- Transformer tapping boost
- Transformer voltage drop
- LV feeder voltage drop
- Voltage drop margin
- Voltage rise margin
- Permissible voltage variation
- Minimum load, substation voltage at its highest value
- Maximum load, substation voltage at its lowest value

Allowable range of substation voltage

1 pu

MV/LV

HV/MV

MV feeder

LV feeder
Why congestion management?

- MV feeder
- LV feeder
- Voltage
- Permissible voltage variation
- Allowable range of substation voltage
- Voltage profiles with generation
- Voltage outside the permissible range
- Permissible voltage variation

- Minimum load, maximum generation, substation voltage at its highest value
- Maximum load, maximum generation, substation voltage at its lowest value
- Maximum load, no generation, substation voltage at its lowest value
Why congestion management?

Active congestion management methods decrease the total costs of the network in many cases.
Control hierarchy of congestion management

- **Secondary control manages resources in one MV or LV network**
  - Mitigates congestions and optimizes the network state
  - Operates through changing the set points of primary controllers
  - Based on state estimation results

- **Tertiary control utilizes forecasts for a longer time interval and manages the whole distribution network**
  - Network reconfiguration
  - Real power control through the market place
  - Dynamic tariff
Interactions of the congestion management system

Day-ahead and Intra-day

- Long-term forecast
  - Dynamic tariff
  - Network reconfiguration and market agent
  - Day-ahead market
  - Flexibility market
  - Commercial aggregator
  - Switch statuses
  - Market

Real-time/intra-hour

- Short-term forecast
  - Monitoring
  - State estimation
  - Secondary control
  - Real-time operation of network reconfiguration and market agent
    - DER scheduling

Hard real-time

- IED, Primary control
  - OLTC, DER
- IED, Real power primary control
  - DER
- IED, Primary control
  - CB

Secondary controller
- Forecasting
- Tertiary controller
- Monitoring Estimation
- Commercial aggregator
- Primary controller
- Primary device
Real time monitoring and secondary control

- Load and production forecast, state estimation and real time power control algorithms are functions of the SAU and are responsible for monitoring and control of either one MV or one LV network.
- All information exchange between the functions is realized through the database.
- Monitoring and load and production forecast functions are executed asynchronously.
- State estimation and power control execution is synchronized by using database flags.
Real time monitoring and secondary control

- The load and production forecast algorithms are time series forecaster algorithms.
- The state estimation algorithm is a weighted least squares state estimator that uses branch currents as state variables.
- The power control algorithm is an optimal power flow (OPF) algorithm implemented using sequential quadratic programming (SQP) algorithm.
  - The objective function is formulated to minimize network losses, production curtailment, load control actions, the number of tap changer operations and the voltage variation at each node.
Network reconfiguration and market agent algorithms

- The network reconfiguration and the market agent algorithms are executed sequentially.
- Both are optimizing algorithms: network reconfiguration utilizes genetic algorithm and the market agent primal/dual interior point algorithm.
• Active Network Management concept
• Distributed automation system
• Congestion management concept
• Demonstrations
• Conclusions
Secondary control demonstrations
Demonstrated in laboratories and real distribution networks

**Day-ahead and Intra-day**

1. Long-term forecast → Dynamic tariff
2. Dynamic tariff → Network reconfiguration and market agent
3. Network reconfiguration and market agent → Commercial aggregator
4. Commercial aggregator → Flexibility market
5. Flexibility market → Day-ahead market
6. Switch statuses

**Short-term forecast**

1. Monitoring → State estimation
2. State estimation → Secondary control
3. Secondary control → Real time operation of network reconfiguration and market agent
4. Real time operation of network reconfiguration and market agent → DER scheduling
5. DER scheduling → Help request

**Control set points**

1. IED, Primary control
2. OLTC, DER

**Hard real-time**

1. IED, Real power primary control
2. DER
3. IED, Primary control
4. CB

**Switch statuses**
Verification of correct algorithm operation → simulation sequences planned to test the algorithm in extreme conditions
• MV and LV secondary control
More realistic simulation sequences
• MV and LV secondary control
PV real power controllable
• LV secondary control

PV reactive power controllable
• LV secondary control

- Lab Demo Site
- Field Demo Site
Tertiary control testing
Network reconfiguration and market agent

Dynamic tariff

Market agent and aggregator functionalities

Lab or Simulation Demo Site
Secondary control
RTDS simulations at TUT laboratory

- RTDS emulates the distribution network
- Real IEDs and a real SAU connected to the simulation
RTDS simulations at TUT laboratory

- RTDS emulates the distribution network
- Real IEDs and a real SAU connected to the simulation
- The simulation network is a reduced model of the real Unareti LV network
  - 6 controllable PV generators (size increased from the real ones)
  - Tap changer at the MV/LV-transformer (not available in the real network)
Operation of the LV secondary control

\[ f = C_{\text{losses}} P_{\text{losses}} + C_{\text{cur}} \Sigma P_{\text{cur}} \]

<table>
<thead>
<tr>
<th>Time</th>
<th>DG output</th>
<th>Loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 s</td>
<td>100 %</td>
<td>MIN</td>
</tr>
<tr>
<td>50 s</td>
<td>30 %</td>
<td>MIN</td>
</tr>
<tr>
<td>230 s</td>
<td>30 %</td>
<td>MAX</td>
</tr>
<tr>
<td>410 s</td>
<td>100 %</td>
<td>MAX</td>
</tr>
</tbody>
</table>
Operation of the LV secondary control

Objective function

\[
f = C_{\text{losses}} P_{\text{losses}} + C_{\text{cur}} \sum P_{\text{cur}} + C_{\text{tap}} n_{\text{tap}} + C_{\text{Vdiff}} \sum (V_{i,\text{ref}} - V_i)^2
\]
Testing interactions between MV and LV secondary control
Adverse interactions do not usually occur \(\Rightarrow\) graded time operation of AVC relays adequate to prevent hunting behaviour
Testing interactions between MV and LV secondary control

<table>
<thead>
<tr>
<th>Time</th>
<th>Feeding network voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0:00</td>
<td>23.0 kV</td>
</tr>
<tr>
<td>1:45</td>
<td>23.5 kV</td>
</tr>
<tr>
<td>3:45</td>
<td>23.0 kV</td>
</tr>
<tr>
<td>5:15</td>
<td>23.3 kV</td>
</tr>
</tbody>
</table>
RTDS simulations at RWTH laboratory

MV and LV Unareti network modeled in the test scenarios

MV and LV grid model implemented for RTDS simulation
RTDS simulations at RWTH laboratory

- **PMUs**
  - delivery of synchrophasors of current and voltage.
- **Smart Meter**
  - delivery of power, voltage and energy data
- **4 virtual IEDs**
  - MMS server developed by RWTH installed
  - IDE4L PostgreSQL database for storing of data
- **PSAU**
  - State estimation and power control developed by TUT installed in Octave environment
  - Load and generation forecasters developed by UC3M installed in Python environment
  - MMS Client developed by Unareti
  - DLMS/COSEM client developed by Unareti
  - OpenPDC client configured by RWTH
  - Postgres SQL Database
- **SSAU**
  - State estimation and power control developed by TUT installed in Octave environment
  - Load and generation forecasters developed by UC3M installed in Python environment
  - MMS Client developed by Unareti
  - MMS Server developed by RWTH
  - DLMS/COSEM client developed by Unareti
  - OpenPDC client configured by RWTH
  - Postgres SQL Database
Operation of the LV secondary control

RMS voltage time profiles for LV nodes in Mid-Season weekend day afternoon scenario

Active Power time profiles for LV nodes in Mid-Season weekend day afternoon scenario

Reactive Power time profiles for LV nodes in Mid-Season weekend day afternoon scenario

Active power generation of DGs

Reactive power generation of DGs
Unareti real network demonstration

Secondary substation involved in the LV test phase
Unareti real network demonstration

- No voltage violations as expected
Unareti real network demonstration

- Reactive power is controlled to minimize losses
Conclusions on secondary control demonstrations

• The algorithms (load and production forecaster, state estimator, secondary power control) operated correctly together

• The secondary control was able to mitigate congestions and to optimize network state

• Graded time operation of AVC relays is usually adequate to prevent adverse interactions between LV and MV secondary control

• The implemented optimization algorithm was in some cases too slow → commercial solver should be used
Tertiary control
Tertiary control operates only at MV level

Assumptions in the market agent calculations:

<table>
<thead>
<tr>
<th>Load type</th>
<th>Power factor</th>
<th>Fixed</th>
<th>Flexible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic</td>
<td>0.9</td>
<td>59%</td>
<td>41%</td>
</tr>
<tr>
<td>Non-domestic (LV)</td>
<td>0.9</td>
<td>53%</td>
<td>47%</td>
</tr>
<tr>
<td>MV load</td>
<td>0.95</td>
<td>53%</td>
<td>47%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of flexibility</th>
<th>Flexibility price (€/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic consumers</td>
<td>0.15</td>
</tr>
<tr>
<td>Non-domestic consumers</td>
<td>0.12*</td>
</tr>
<tr>
<td>MV consumers</td>
<td>0.09</td>
</tr>
</tbody>
</table>

*Obtained by interpolation.
Operation of network reconfiguration algorithm

- The first section of feeder 1 between nodes PS0023 and 545 is loaded at 102.5% of its nominal capacity.
- Network reconfiguration algorithm operates and shifts part of the load of feeder 1 to feeder 2 by opening the breaker 468-827 and closing the breaker 603-117.
Operation of the market agent algorithm

- Line section at the beginning of feeder 3 between nodes PL2 and 1056 is loaded at 104.24 % of its nominal capacity
- Market agent algorithm purchases flexibility products to mitigate the congestion
Also economical evaluation is needed

• Demonstrations verify the correct operation of the implemented automation architecture and algorithms but do not tell anything on the cost-efficiency of alternative methods ⇒ also network planning methods have to be developed

• Congestion management affects both CAPEX and OPEX
  • Yearly operational costs of alternative methods can be calculated using hourly load flow calculations (losses, cost of curtailed generation etc.)
  • Investment costs of alternative methods consist of network reinforcement costs and/or costs of automation system
  • The network total costs can be compared by combining the investment cost annuities and yearly operational costs
• Active Network Management concept
• Distributed automation system
• Congestion management concept
• Demonstrations
• Conclusions
Results

1. Active network management concept
2. Hierarchical and decentralized automation architecture
3. Distribution grid and DER management functionalities
4. Benefits and impacts of functionalities for DSO
5. Demonstrations of concept, architecture and functionalities in three field demonstrations
6. Recommendations and roadmap
Substation Automation Unit

- Control Center - DMS
- Substations - IEDs
- Prosumers – Smart meters and DER IEDs
- DLMS/COSEM
- MMS
- Interfaces
- Database
- Applications
- Reports
- Data Acquisition
- State Estimation
- Forecast
- Power control
- Management model
- CIM
- Bridge model
- IEC 61850
Conclusions

• **Basis for distributed grid management and interaction of business players**
  - Design, implementation and demonstration of ANM, hierarchical and distributed automation architecture and commercial aggregator concepts

• **Efficient utilization of grid assets**
  - Monitoring and control of complete grid
  - Increased hosting capacity for RESs and DERs
  - Enhanced reliability of power supply
  - Planning tools estimate the hosting capacity increment
Conclusions

• Scalability of automation solution
  • Automation is based on existing devices → allows to gradually deploy the new solutions
  • The same architecture and cores of the automation are suitable for both primary and secondary substations
  • Functions can be deployed locally and coordinated
  • Local functions are light, makes integration scalable
  • Vertical and horizontal integration provides a complete view of the distribution network status
  • Data exchange between DSO and aggregator to validate, purchasing and activating flexibilities will further extend ANM capabilities
Conclusions

• **Utilization and development of standards**
  - IEC61850, DLMS/COSEM (IEC 62056) and CIM (IEC 61970/61968) for architecture and implementation
  - The interoperability has been achieved through:
    • Identification of interfaces and information exchange synthesized from the IDE4L use cases.
    • The automation architecture was hence derived and defined based on the SGAM framework.
  - Implementations of automation system have been demonstrated in three demonstration sites
Thank you!

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