Day 2

INCREASE Agent Based Control View

Andrej Gubina
As. Professor
Faculty of E&C Engineering
University of Lubljiana

Grigoris Papagiannis
Professor, Director
Power Systems Laboratory
School of E&C Engineering
Aristotle University of Thessaloniki
INCREASE is an EU funded FP7 project, oriented at delivering tools and solutions to DSOs for the future smart grids.

To ensure that these tools and solutions are well accepted and fit the needs of this target group as much as possible, 4 DSOs from different regions in Europe are partners in the project, apart from research institutions and industrial partners.
The INCREASE consortium

Austria:
- Joanneum Research
- Energienetz Steiermark

Belgium
- Eandis
- Elia
- Ghent University

Greece
- Aristotle University of Thessaloniki
- ILPRA SA

Slovenia:
- Elektro Gorenjska
- Korona
- University of Ljubljana

The Netherlands:
- Liander
- Mastervolt
- Technische Universiteit Eindhoven
Outline

1. Challenges on LV Distribution Networks

2. Description of INCREASE Control Schemes
   a. Local Control
   b. Overlaying Control
   c. Scheduling Control

3. The LAN Simulator Component

4. The INCREASE Integrated Simulation Platform

5. Next Steps
LV Distribution Networks

Conventional LV Networks
Designed based on a unidirectional power flow scheme from utility to end-users

Operational Objective
Maintain voltages within permissible levels in accordance to EN 50160 ($U_N \pm 10\%$)

- Compensation of the voltage drop along the power line
- Stationary adjustment of the transformer ratio (on-load?)

Source: Dr. Bernhard Ernst, EPIA-EDSO for Smart Grids Conference on Grid Management, 24 June 2014, Brussels, Belgium
Advent of Distributed Generation (DG)
DG units are located close to loads

Major Challenges
Transition from a unidirectional to a bidirectional power flow scheme

Overvoltage and possible violation of EN 50160  → Limited DG penetration

Source: Dr. Bernhard Ernst, EPIA-EPSO for Smart Grids Conference on Grid Management, 24 June 2014, Brussels, Belgium
Other Technical Issues
DG not uniformly distributed among phases  ➔  Considerable voltage unbalances

Congestion issues on power lines and/or on transformers

Traditionally not monitored  and/or controlled

Source: Dr. Bernhard Ernst, EPIA-EDSO for Smart Grids Conference on Grid Management, 24 June 2014, Brussels, Belgium
LV Distribution Networks

Possible Solutions (1/2):

Reinforcing the distribution feeders or implementing electric energy storage
- Reduces network losses
- Increases feeder capacity
- Needs investments

Use of OLTCs and/or voltage regulators
- Active voltage regulation
- No interference with DG units operation
- Needs investments
- Reliability issues
- Operational limitations
Possible Solutions (2/2):

Employing reactive power control techniques
- ✅ Avoids active power curtailment
- ❌ Limited by inverter rated power
- ❌ Inefficient for LV networks with high $R/X$ ratio
- ❌ Increases network losses

Introducing active power curtailment
- ✅ Occurs only at high generation periods
- ✅ Efficient for LV networks
- ✅ Increases DG penetration
- ❌ Revenue loss for DG units owners
The INCREASE Control Schemes

Conceptual Design

- Optimized network operation → Scheduling Control (intra-hour day, etc.)
- Active management of LV distribution networks → Overlaying Control (min)
- Mitigation of overvoltages and of voltage unbalances → Local Control (ms)

Outcome

Increase the penetration of DG units in existing networks
Enhance the observability and controllability of LV networks
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Local Control Overview

Objective
Real-time mitigation of overvoltages and of voltage unbalances

Main Aspects
- Low-level control scheme
- Immediate reaction on changes of grid operational state
- Enhancing the smooth/safe operation of the distribution grid
- Stand-alone operation, use of local parameters (e.g. voltage at the PCC)

Diagram:
- MV/LV
- Load
- CM: Current Measurement
- VM: Voltage Measurement
- AG: Agent
- DG

www.project-increase.eu
Local Control Overview

**Actual Implementation**

Applied to DG units via INCREASE developed controllable grid-interfaced inverters

Two basic control schemes are incorporated

- The droop control of the injected real power → avoid ON/OFF oscillations
- The voltage unbalance mitigation control
Local Control Overview
An implementation example

Examined Control Schemes
• No control (NC)
• Voltage unbalance mitigation control (VUMC)
• Droop control (DC)
• Combined operation of DC and VUMC (DC & VUMC)
Local Control Overview
An implementation example

No control (NC)
- Unacceptable overvoltages along the feeder
- 3rd DG is switched off
- Loss of power

![Graph showing positive-sequence voltage (pu) across nodes with NC, VUMC, and upper threshold (EN 50160)]
Voltage unbalance mitigation control (VUMC)
Mitigation of voltage asymmetries
✓ $VUF_0$ is reduced considerably
✗ $VUF_2$ is slightly deteriorated

Voltage unbalance factors (VUF) are defined as:

\[
VUF_0(\%) = \frac{V_0}{V_1} \times 100\% \quad VUF_2(\%) = \frac{V_2}{V_1} \times 100\%
\]
Local Control Overview
An implementation example

Phase-to-Neutral Voltages (pu)

Nodes

VAN NC
VBN NC
VCN NC
VAN VUMC
VBN VUMC
VCN VUMC
Voltage unbalance mitigation control (VUMC)

- Mitigation of voltage asymmetries
- **Unacceptable overvoltages** (at nodes 6 & 7)
- Disconnection of DG units
- Loss of power
Local Control Overview

An implementation example

Introduction of Droop Control (1/3)
LV grid distribution lines have a high $R/X$ ratio

Efficient voltage control can be achieved by controlling the injected real power of the DG units

![Diagram showing droop control](image)

Outcomes
- Unacceptable overvoltages along the feeders can be avoided by curtailing part of the injected real power of the DGs
- DG unit switch-offs due to overvoltages are avoided
Local Control Overview
An implementation example

Droop control (2/3)
- The voltage profile along the feeder is actively controlled
- Overvoltages are efficiently mitigated
- No DG unit is switched off
Local Control Overview
An implementation example

Droop control (3/3)

✓ $VUF_0$ is decreased

✗ $VUF_2$ is increased

✗ Voltage asymmetries are not sufficiently mitigated
Combined operation of DC and VUMC (1/2)

NC and VUMC control overlap

DC and the combination of DC with VUMC control schemes overlap

✓ The proposed control reduces overvoltages
Local Control Overview
An implementation example

Combined operation of DC and VUMC (2/2)
✓ $VUF_0$ is further reduced
✓ $VUF_2$ remains almost unaffected
✓ Voltages asymmetries are effectively mitigated
Local Control Overview
A field trial example
# Local Control Overview

## Synopsis

<table>
<thead>
<tr>
<th>Droop Control (DC)</th>
<th>Voltage Unbalance Mitigation Control (VUMC)</th>
<th>Combined operation of DC and VUMC</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓ Overvoltages are reduced</td>
<td>✓ Voltage asymmetries are tackled</td>
<td>✓ Unacceptable overvoltages are avoided</td>
</tr>
<tr>
<td>✗ Voltage unbalances are not efficiently mitigated</td>
<td>✗ It cannot control overvoltages</td>
<td>✓ Higher penetration of DG units is feasible</td>
</tr>
<tr>
<td></td>
<td></td>
<td>✓ Voltage unbalances are mitigated</td>
</tr>
</tbody>
</table>

Combined operation of DC and VUMC results in:
- Unacceptable overvoltages are avoided
- Higher penetration of DG units is feasible
- Voltage unbalances are mitigated
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Overlaying Control Overview

Objectives

- Uniform active power curtailment among DG units of the same feeder
- Use of OLTC to actively control network voltages
- Congestion management

Main Aspects

- Centralized and middle-level control scheme
- Moderate response (15-minutes)
- Increasing the energy capture from DG units
- Enhancing the safe operation of the distribution grid
Overlying Control Overview

Proposed Algorithms

Fair power sharing control (FPS)
- Uniform active power curtailment
- Use of the sensitivity matrix

OLTC control
- Maintain network voltages within limits
- Reduce the curtailed power of DG units

Congestion management
- Transformer protection from overloading
- Active power curtailment of DG units
Overlaying Control Overview

**Conceptual design**
15 minutes timeslot

First 5 minutes: Only Local Control

Remaining 10 minutes: Activation of Overlaying Control
Overlaying Control Overview

Distributed Multi-Agent System (MAS)

Hierarchical Architecture (Agent-Aggregator)

An Agent in each controllable DG unit

Aggregator is usually sited at the DSO

Wired or Wireless communication
Overlaying Control Overview
An implementation example

Network characteristics
- 79 buses
- 70 unbalanced time series loads
- 30 PV installations

Examined Control Schemes
- No control (NC)
- Local Control (Local)
- Local & FPS (LF)
- OLTC & Local (OL)
- OL & FPS (OLF)
- OLF & Congestion (OLFC)
Comparative results along a feeder (1/2)

**No Control (NC)**
- ✓ No active power curtailment
- ✗ Severe overvoltages at the last nodes

**Local Control (Local)**
- ✓ Efficient overvoltage mitigation
- ✗ Non-uniform active power curtailment along the feeder

**Local and FPS Control (LF)**
- ✓ Uniform active power curtailment
- ✗ Increased overall active power curtailment compared to Local Control
Comparative results along a feeder (2/2)

**OLTC and Local (OL)**

- Less active power curtailment compared to the Local Control
- Effective overvoltage mitigation
- Non-uniform active power curtailment among DG units

**OLTC, Local and FPS (OLF)**

- Effective overvoltage mitigation
- Uniform active power curtailment
- Increasing the overall injected active power compared to the LF scheme
Overlaying Control Overview
An implementation example

Time series simulation (1/5)
• 15 minutes timeslot concept
• Execution time: **less than 2 minutes** for a time period of 24 hours
• Considering the different control schemes, similar conclusions can be drawn about the total injected power
• For most of the time, OL and OLF overlap
Overlaying Control Overview
An implementation example

**Time series simulation (2/5)**
- The OL control scheme minimizes the curtailed power
- However, the OLF applies a more uniform active power curtailment among the DG units of the same feeder
- Superior performance of the OLF in comparison with the other control schemes
- Network losses proportional to the generation due to reverse power flow
- Network voltages are actively controlled
Overlaying Control Overview
An implementation example

Time series simulation (3/5)

a) NC

b) Local

c) LF

d) OL

e) OLF
Overlaying Control Overview
An implementation example

Time series simulation (4/5)

- Only two tap changes are performed during the day
- OLTC is not stressed

- The energy capture from DG units is increased due to the OL and OLF control schemes
Time series simulation (5/5) - An Extreme Case

- The installed capacity of PV units is increased to cause congestion at the transformer
- OL and OLF control schemes are not able to tackle the excessive power flow
- OLFC relieves the stress from the transformer
- Results in decreased produced energy compared to OL and OLF schemes
Overlaying Control Overview

Synopsis (1/2)

- Local Control
  - ✔ Efficiently mitigate overvoltages
  - ✗ Unequal active power curtailment

- Local & FPS Control
  - ✔ Redistributes uniformly the curtailed power to the DG units
  - ✗ Overall curtailment is increased

- OLTC & Local Control
  - ✔ Results in less active power curtailment compared to Local Control
Overlaying Control Overview

Synopsis (2/2)

- OLTC & Local & FPS Control
  - Presents a superior performance compared to LF control scheme, concerning active power curtailment

- OLTC & Local & FPS & Congestion Control
  - Enhanced OLF control scheme
  - Able to handle transformer congestion issues
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## Scheduling Control Overview

### Objectives
- Minimize the number of undervoltage/overvoltage violations and current congestion issues by employing demand response (DR) techniques
- Maximize the profit of DR units

### Main Aspects
- Centralized and high-level control scheme
- Maximizing the green energy injection
- Slow response (intra-hour, day, day-ahead, etc.)
- Optimizing the operation of the distribution grid
Conceptual design

- Top hierarchical layer
- Use of forecast tools and price signals from wholesale electricity market
- Responsible for the coordination of the lower level control layers (Local and Overlaying Control)
- Introduction of a ‘traffic light system’ approach

- 4 time layers:
  - Tertiary reserve market \((t > 168 \text{ h})\)
  - Day-ahead market \((t > 24 \text{ h})\)
  - Intraday market \((1 < t < 24 \text{ h})\)
  - Balancing market \((15 \text{ min} < t < 1 \text{ h})\)
### Scheduling Control Overview

#### Actual implementation
- Distributed Multi-Agent System (MAS)
- Hierarchical Architecture (Agent-Aggregator)
- Development of Scheduling Control Agent (SCA) aggregator
  - Responsible for the dispatch of DR units
- Cooperation with the Overlying Control Agent (OCA) aggregator
Synopsis

- Optimization criterion includes the maximum profit (including income from the markets, non-performance penalties for DR units)

- Results in optimal use of flexible energy available from Demand Response
- Maximizing the DRES operation (minimal curtailment)
- No power quality violations
- Pricing is tied to day-ahead, intraday and balancing markets
- Helps maximizing the effectiveness of Overlaying Control

- Simulation setup is under development
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LAN Simulator Component Overview

Objective

Evaluate the communication traffic between agents and aggregator

Main Aspects

Ability to examine different communication technologies
- Wired (fiber, PLC)
- Wireless (Wi-Fi, GPRS)

Offers a variety of features and calculations
- Time delays
- Reliability
- Necessary bandwidth
- Loss of pockets

Test of different communication protocols (TCP, UDP)
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The INCREASE Simulation Platform

Objectives

Evaluate the effectiveness of the proposed control schemes
Simulate extended networks fast and reliably

MATLAB

Draw
Simulink Designing Tool

JADE
Agents’ Environment

OMNeT++
LAN Simulation Framework

OpenDSS
Distribution System Simulator
Incorporation of the Local Control to the Simulation Platform

- Two software development tools are used
- OpenDSS, as a unbalanced power flow solver
- MATLAB, where the basic control schemes are modeled
Incorporation of the Overlaying Control to the Simulation Platform

- Three software products are employed
  - OpenDSS, as a unbalanced power flow solver
  - JADE, as a MAS developing environment
  - MATLAB, which is responsible for the coordination between Local and Overlaying Control
Scheduling Control Overview

Incorporation of the Scheduling Control to the Simulation Platform (1/2)

- Three software products are employed
- OpenDSS, as a unbalanced power flow solver
- JADE, as a MAS developing environment
- MATLAB, which is responsible for the coordination of Local, Overlaying and Scheduling Control
Incorporation of the Scheduling Control to the Simulation Platform (2/2)

- First, the DR algorithm optimizes for market pricing and flexibility taking into account grid constraints
- Then, a power flow analysis is introduced. Depending on the results, another iteration is initiated or they are forwarded to the ‘Real Time’ layer
- This setup can run in any timeframe/layer (intraday, day-ahead, etc.)
LAN Simulator Component Overview

Incorporation of the LAN simulator to the Simulation Platform

- MATLAB converts the data (network topology, location of agents, type of communication) in executable forms for OMNeT++ (NED & INI files)
- A variety of simulations can be carried out by OMNeT++
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Next steps

- **Next Steps**
  - Finalizing the GUI-DRAW component
  - Enhance the capabilities of the Overlaying control
    - Introducing appropriate weighted actors
    - Opportunity to simulate different pricing policies
    - Categorize users based on various (user-defined) criteria
  - Further validation and fine tuning of the simulation models based on cross comparisons of simulation results
    - Lab measurements
    - Field measurements (pilot installations)
Thank you very much for your attention!

Questions?