Automatic functions for coordinated power flow control
Agenda

• Chapter 1 – ENSURE
  • Overview & Concept
  • Test system and scenario setup
  • Exemplary simulation results
  • Violation of network restrictions

• Chapter 2 – IDEAL
  • Motivation
  • Agent based power flow control
  • Laboratory setup
Chapter 1 | ENSURE CROSS VOLTAGE LEVEL POWER FLOW CONTROL
Increase of volatile and distributed generation

Shut-down of the conventional power plants

New strategies for system control are necessary

**Possible approach:** Control power flows between several voltage levels

- The STG-CS uses DERs connected to the STG and subordinated DG-CSs as actuators

- The DG-CSs uses DERs connected to the DG as actuators

Schedules (transfer rate e.g. 15 min)

Setpoints (transfer rate in the range of seconds)

Measurement

Flexible Load

Distributed Energy Resources (DERs)
ENSURE | Test system and scenario setup

- Dynamic simulations in Matlab-Simulink to proof concept
- The System is in initial state at t=0s
  - DG2 the load increases by 10 MW at t=1s
  - Case I: DG2 is able to compensate the change of load independently
  - Case II: In DG2 is not enough flexibility available to compensate the loadstep independently

Feeder 1 of the CIGRE MV benchmark network

Diagram:
- STG-0
- STG-1
- STG-2
- STG-3
- DG1
- DG2
- DG3
- STG-CS
- P_Flex
- P_L
- 7 MW
- 13 MW
- 4 MW
- 10 MW
- 4 MW
- 4 MW
- 13 MW
- 7 MW

Loadstep: 10 MW
ENSURE | Exemplary simulation results – Case I

(a) Active Power Flow between STG and TG

(b) Active Power Flows DG/STG and Residual Load STG
ENSURE | Exemplary simulation results – Case II

(a) Active Power Flow between STG and TG
- $P_{STG\ ref}^{\ STG}$
- $P_{STG\ meas}^{\ STG}$
- 10%-band

(b) Active Power Flows DG/STG and Residual Load STG
- $P_{DG1\ meas}^{\ DG1}$
- $P_{DG2\ meas}^{\ DG2}$
- $P_{DG3\ meas}^{\ DG3}$
- $P_{STG\ res}^{\ STG}$
ENSURE | Violation of network restrictions

- The CS is blocked when network restrictions are violated.
- The CS restarts operation when problems are solved.
- How could congestions in future electrical power supply system be solved?
Chapter 2 | IDEAL
AGENT BASED CURATIVE CONGESTION MANAGEMENT
IDEAL | Motivation

- Curative congestion management:
  - Operating lines closer to their capacity limit
  - Enabling higher utilization of available transmission capacity
  - Use of distributed power flow controllers and flexible infeed from active distribution networks

- Agent based approach:
  - Distributed control algorithm
  - Autonomous determination of countermeasures
  - Support of control center staff

- Validation in laboratory setup:
  - Testing interconnection between control center, communication system and power flow controller
  - Implementation using commercially available products and industry standards
**Hardware Components**

Control Center

Sub-Transmission Grid (STG)

Distribution Grid (DG)

- Smart Telecontrol Unit in STG
- Smart Telecontrol Unit in DG
- Flexible Load
- Flexible Generator

**Information Flow & Decision Making**

- Measurements & Setpoints
- State Inform Message & Negotiation of Actions
- Line Overload

- CFP: +ΔX
- DPFC Setpoint

- Q\(_{\text{flex}}\)
- P\(_{\text{flex}}\)
IDEAL | MAS information flow

State Inform Message:
- Contains:
  - line loading,
  - Impedance
  - connected nodes

- Information is exchanged periodically between agents
- Distribution limited to relevant agents
- Current system state is known for relevant area to all agents
IDEAL | MAS decision making

Information exchange → Monitoring and Decision Making → Decision and Control Action

Detection of line overload

Call for proposal
Responsible Agent calls for available flexibility:
- Flexibility of underlying grids
- Available PFC flexibility
Line overload present

Choosing flexibility accordingly:
- PFC flexibility before flexible loads and generation
- Highest sensitivity on overloaded line first
- No additional overloads are created
- DC sensitivities calculated using information from State Inform Messages
IDEAL | MAS executing control action

Option 1: Propose control action to control center (semi-autonomous)

- Send proposal to control center
- Assessment of proposal by control center staff
- Activation of flexibility by control center
IDEAL | MAS executing control action
Option 2: Autonomous execution of control actions

- Activation of control action by agent
- Send information of performed control action to control center
IDEAL | Simulation setup: New England Test System

- Power Flow Controller installed on line TL0415
- Active Distribution Network at Node 5 and 15
- Line outage on TL0506 causes overload on TL 0414
- Overload resolved by countermeasures determined by MAS
- Use of power flow controllers and flexibility from active distribution networks
IDEAL | Exemplary Simulation results

Outage of line TL0506 at t=5s

Loading of line TL0414

Loading of line TL0405

ADN Flexibility

Power Flow Controller
IDEAL | Laboratory Setup: Real-time simulation and Power hardware-in-the-loop

- Real-time digital simulator OPAL RT
  - eMegasim simulation software
  - IEC 104 measurement transmission
  - Analog signal output

- Power amplifiers
  - 200 kVA
  - AC, DC operation
  - Voltage & Current mode
  - Internal measurement system (4 µs minimum delay)
IDEAL | Laboratory Testbed

Simulated Elements

Hardware Elements

IEC 60870-5-104 Communication

Non-Standardized Communication Protocol

Control Center

PSI Control

Real-Time Simulator

PSI STUs (Agents)

Control actions and measurements

Grid Model and MAS

Impedance Controllers

Smart Wires Powerline Guardian

Power Amplifier

Controller Set Points

Simulated Elements

Hardware Elements

IEC 60870-5-104 Communication

Non-Standardized Communication Protocol

Control Center

PSI Control

Real-Time Simulator

PSI STUs (Agents)

Control actions and measurements

Grid Model and MAS

Impedance Controllers

Smart Wires Powerline Guardian

Power Amplifier

Controller Set Points

Simulated Elements

Hardware Elements

IEC 60870-5-104 Communication

Non-Standardized Communication Protocol

Control Center

PSI Control

Real-Time Simulator

PSI STUs (Agents)

Control actions and measurements

Grid Model and MAS

Impedance Controllers

Smart Wires Powerline Guardian

Power Amplifier

Controller Set Points
Conclusion and Outlook

Accomplishments:
• Distributed generation can be controlled to follow scheduled power flows at interconnection points
• Multiagent Systems can be implemented to use power flow controllers and flexible load and generation for corrective congestion management

Next steps:
• Integration of agent based congestion management and control of distributed generation
  ➢ Increased autonomous grid operation relieves grid operators and enables high shares of renewable energies
• Consider real world and market conditions!