Leveraging Consumers’ Flexibility for the Provision of Ancillary Services

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DTU  ENERGINET  CITIES
Centre for IT Intelligent Energy Systems
Agenda

- Introduction
- Innovative solution for unlocking consumers’ flexibility potential: Ancillary Services 4.0
- Modelling of the Ancillary Services 4.0 approach
- Results
- Concluding remarks
Introduction
Context and motivation

Power system operation in the past

Operation almost predictable and controllable

Conventional generation units
Reactive and passive consumers

High voltage
Medium voltage
Low voltage
Introduction

Context and motivation

Power system operation today

Operation **more stochastic** and **less controllable**

Intermittent **renewable** generation units
Active and **dynamic** consumers
Introduction
Context and motivation

Challenges for the power system operation

Increasing complexity
- Stochasticity
- Non linearity
- Dynamics

Higher need of stability
- Higher demand of **ancillary services** (AS)

Uncertainty of AS provision
- Conventional generation units operating under rated capacity
- Retirement of conventional generation units
- International climate targets
  - Denmark: 2030: 70% CO2 reduction
  - 2050: CO2 neutrality

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**Introduction**

Key concepts in power systems

**Demand response programs**

In demand response (DR), consumers alter their consumption according to the necessity of the grid.

![Graph showing consumption over time](image)
Introduction
Key concepts in power systems

Demand response programs

In demand response (DR), consumers alter their consumption according to the necessity of the grid.

Explicit DR programs
- Minimised uncertainty
- Consumers’ privacy

Implicit DR programs
- Consumers’ autonomy
- Effective price signals
Unlocking consumers’ flexibility potential
General framework for AS provision

Research question

Which framework can help to optimally exploit consumers’ flexibility for AS provision at different voltage levels?
Unlocking consumers’ flexibility potential
General framework for AS provision

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Which framework can help to optimally exploit consumers’ flexibility for AS provision at different voltage levels?

Ancillary Services 4.0 - core idea

1. Time-varying prices
2. Adoption of controllers
3. One-way communication

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**Research question**

Which framework can help to optimally exploit consumers’ flexibility for AS provision at different voltage levels?

**Ancillary Services 4.0 - core idea**

- Power system operators
- Electricity consumers

**Requirements**

- Dynamics
- Non linearity
- Stochasticity
- Services at TSO / DSO
- Fast
- Cost effective
- Consumers’ autonomy / privacy
- Scalable

1. Time-varying prices
2. Adoption of controllers
3. One-way communication
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Research question
Which framework can help to optimally exploit consumers’ flexibility for AS provision at different voltage levels?

Ancillary Services 4.0 - core idea
Power system operators
Electrical consumers

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Non linearity
Stochasticity
Services at TSO/DSO
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2 Adoption of controllers
3 One-way communication

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Required models for AS4.0

Three types of models are needed to formulate AS4.0

- Transmission system control model
- Distribution system control model
- Consumers’ price response model
- Consumers’ effective flexibility response

External power disturbance

Models
Unlocking consumers’ flexibility potential
General framework for AS provision

Required models for AS4.0

Three types of models are needed to formulate AS4.0

1. **Power system control models**
   - Effect on frequency/voltage
   - Needed flexibility
Unlocking consumers’ flexibility potential
General framework for AS provision

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1. **Power system control models**
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2. **Consumers’ price response models**
   - Consumers’ responsiveness toward prices
   - Proper price signals
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General framework for AS provision

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   - Consumers’ responsiveness toward prices
   - Proper price signals

3. **Effective flexibility response models***
   - Actual consumers’ behaviour
   - Achieved flexibility

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*Effective flexibility response models are marked with an asterisk.
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Power system control models
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Power system control models

- Load frequency controller (LFC)
- Transmission system
- Power exchange
- Power flow (PF)
- Distribution system
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At the transmission level

Two-area LFC
Comparison of performance between conventional generation units and AS4.0
Unlocking consumers’ flexibility potential
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Power system control models

At the transmission level

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Power system control models

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At the distribution level
Unlocking consumers’ flexibility potential
General framework for AS provision

Aggregate consumers’ price response
Unlocking consumers’ flexibility potential
General framework for AS provision

Aggregate consumers’ price response

Dynamic price formulation

Introduction
AS4.0
Modelling
Results
Conclusions

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General framework for AS provision
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Aggregate consumers’ price response

Data can be used to model consumers’ reaction toward prices.
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Data can be used to model consumers’ reaction toward prices.

Aggregate consumers’ price response

Electricity consumption

Time-varying electricity price

Temperature

Type of consumer

…

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Aggregate consumers’ price response

Data can be used to model consumers’ reaction toward prices.

Due to data scarcity, models are adopted.

Different models at transmission and distribution levels:

- Size
- Consumers’ composition
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Aggregate consumers’ price response

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Different models at transmission and distribution levels:
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- Consumers’ composition

At the transmission level

Frequency is not a local issue

Model
- Montecarlo simulation
- Neural network

Aggregate consumers’ flexibility
- Cost minimisation
- Aggregate flexibility
- Time varying prices
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Montecarlo simulation

Neural network

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→ Aggregate flexibility
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At the transmission level

Frequency is **not** a local issue

**Model**
- **Monte Carlo simulation**
- **Neural network**

→ Cost minimisation
→ Aggregate flexibility
→ Time varying prices

At the distribution level

Voltage is a local issue

**Model**
- PI controller

→ Flexibility at each DSO bus
→ DSO buses clustering
→ Consumers’ willingness
→ Voltage deviation
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Simulation results

Frequency at the transmission level

AS4.0 reduces the frequency deviation by around 50% compared to the conventional method.

![Graph showing frequency deviation](image)

<table>
<thead>
<tr>
<th>Time and disturbance injected, (sec, MW)</th>
<th>Maximum frequency deviation, Hz</th>
<th>Deviation reduction, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>[1,1000]</td>
<td>0.10</td>
<td>40 %</td>
</tr>
<tr>
<td>[30,350]</td>
<td>-0.27</td>
<td>52 %</td>
</tr>
<tr>
<td>[60, 852]</td>
<td>0.21</td>
<td>38 %</td>
</tr>
<tr>
<td>[90, 500]</td>
<td>-0.26</td>
<td>38 %</td>
</tr>
<tr>
<td>[120, 1148]</td>
<td>0.20</td>
<td>40 %</td>
</tr>
<tr>
<td>[150, 1000]</td>
<td>-0.12</td>
<td>33 %</td>
</tr>
<tr>
<td>[180, 1300]</td>
<td>0.14</td>
<td>42 %</td>
</tr>
<tr>
<td>[210, 1056]</td>
<td>-0.17</td>
<td>35 %</td>
</tr>
<tr>
<td>[240, 1500]</td>
<td>0.12</td>
<td>41 %</td>
</tr>
</tbody>
</table>
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Simulation results

Voltage at the distribution level

AS4.0 manages to **mitigate** the voltage issues at the DSO buses.

Operational issues at TSO and DSO

The **number of buses** with voltage issues **decreases** over time.
Concluding remarks

Conclusions

Electricity consumers have high potential to provide flexibility to the grid.

AS4.0 is a new approach for AS provision which is based on:

- time varying electricity prices
- one-way communication
- control techniques

It successfully handled the operational issues at TSO and DSO level.

AS4.0 achieved better performance than the conventional generation units-based method.
Thank you!