Utilizing Flexibility Resources in the Future Power System Operation: Alternative Approaches

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Outline

- Motivations
- Coordinating flexible resources
- Different approaches in literature: market versus control
- Proposed methodology: AS4.0
- Estimating the available flexibility
- Conclusions
The electricity supply service
Challenges introduced by RES

Adding RES to the generation portfolio affects the quality of service and power system operation because of:

**Stochasticity**

The generation from RES **cannot be planned** in the same way as conventional power plants.

**Non-linearity**

The generation can follow a **non-linear trend** in spite of the linear bidding and clearing process.

**Dynamics**

**Voltage** and **frequency** levels **fluctuate** due to the power imbalance.
The electricity supply service
Consequences for the AS

This is particularly affecting the provision of the ancillary services:

- Congestion management
- Frequency management
- Balancing
- Voltage management
- Transmission
- Distribution
The electricity supply service
Exploiting the energy flexibility

Flexible resources

Flexible loads, energy storage and generation are able to adapt their behaviour according to the necessity of the grid.

They need to be coordinated in a fast and efficient manner in order to be valuable.
Coordinating the energy flexibility
AS provision operation

In order to coordinate the energy flexibility, it is important to develop an approach that satisfies all the different requirements of the smart grid era.

Literature considers various approaches:

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Requirements

- Stochasticity
- Non-linearity
- Dynamics
  - Certainty of the response
  - Energy system integration
  - DS management
  - TS management
  - Prosumer privacy

- Scalable
  - Simple
  - Fast
  - Secure
  - Cheap
Coordinating the energy flexibility

The electricity price

The submission of time-varying electricity prices can support the exploitation of the price responsiveness for flexible energy resources.

Nowadays, the wholesale electricity price is flexible and changes sub-hourly through a market and clearing process.

However, the retail electricity price is fixed by the utility and does not change over time.
Coordinating the energy flexibility
Market-based operation

Transactive energy

It involves an agent to **aggregate** DERs. It formulates bids from **feedback** signals communicated with the consumers.

- Certain response
- Distribution system management
- Deterministic, linear and static
- Two-way communication
- Slow
Coordinating the energy flexibility
Market-based operation

P2P

It is a coordinated multi-lateral trading framework which avoids the interference of the middle man.

- Scalable
- Stochastic, non-linear and dynamic
- No transmission system management
- Purely financial

Motivations
Flexibility
Literature
AS4.0
Availability
Conclusions
Coordinating the energy flexibility
Control-based operation

Control-based approach

It adopts **controls** at the lowest level of the grid. Consumers are managed by **aggregators** through indirect and direct controls. Market is maintained at the highest level.

- It can use one-way communication
- Stochastic, non-linear, and dynamic
- Dependency on the market
- No transmission system management
Coordinating flexible resources

AS4.0: Idea

What if system operators could formulate real-time varying prices according to the flexibility needed and exploit a one-way communication?
Coordinating flexible resources

AS4.0: Idea

What if system operators could formulate real-time varying prices according to the flexibility needed and exploit a one-way communication?
Coordinating flexible resources
AS4.0: Structure

Control-based approach

\[
\min_{\mu} \mathbb{E}\left[ \sum_{k=0}^{N} w_{j,k}\|\hat{z}_k - z_{\text{ref},k}\| + \mu\|p_k - p_{\text{ref},k}\| \right]
\]

s.t. \( \hat{z}_{k+1} = f(p_k) \)

Model predictive control

\[
\min_u \mathbb{E}\left[ \sum_{k=0}^{N} \sum_{j=1}^{J} \phi_j(x_{j,k}, u_{j,k}, p_k) \right]
\]

s.t. \( x_{k+1} = Ax_k + Bu_k + Ed_k, \)
\( y_k = Cx_k, \)
\( y_k^{\text{min}} \leq y_k \leq y_k^{\text{max}}, \)
\( u_k^{\text{min}} \leq u_k \leq u_k^{\text{max}} \)
Coordinating flexible resources

AS4.0: Structure

Deviation minimisation

\[
\min \Delta \lambda_{t}^{TSO} \sum_{t=1}^{\tau} U_{t} \\
\text{s.t.} \quad \sum_{t=1}^{\tau} \Delta \lambda_{t}^{TSO} = 0 \\
\quad |\Delta \lambda_{t}^{TSO}| \leq U_{t} \quad \forall t \\
\quad |\Delta \lambda_{t}^{TSO} - \Delta \lambda_{t}^{TSO}'| \leq \epsilon \Delta \lambda_{t}^{TSO}' \\
\quad U_{t} \geq 0 \quad \forall t
\]

Control-based approach

\[
\min_{p} \quad E\left[ \sum_{k=0}^{N} w_{j,k} |\hat{z}_{k} - z_{ref,k}| + \mu |p_{k} - p_{ref,k}| \right] \\
\text{s.t.} \quad \hat{z}_{k+1} = f(p_{k})
\]

Model predictive control

\[
\min_{u} \quad E\left[ \sum_{k=0}^{N} \sum_{j=1}^{J} \phi_{j}(x_{j,k}, u_{j,k}, p_{k}) \right] \\
\text{s.t.} \quad x_{k+1} = Ax_{k} + Bu_{k} + Ed_{k}, \\
\quad y_{k} = Cx_{k}, \\
\quad y_{k}^{min} \leq y_{k} \leq y_{k}^{max}, \\
\quad u_{k}^{min} \leq u_{k} \leq u_{k}^{max}
\]
Motivations

Flexibility

Literature

AS4.0

Availability

Conclusions

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Coordinating flexible resources

**AS4.0: Structure**

Control-based approach

\[
\min_p \mathbb{E}\left[ \sum_{k=0}^{N} w_{j,k} ||\hat{z}_k - z_{ref,k}|| + \mu||p_k - p_{ref,k}|| \right] \\
\text{s.t.} \quad \hat{z}_{k+1} = f(p_k)
\]

Model predictive control

\[
\min_u \mathbb{E}\left[ \sum_{k=0}^{N} \sum_{j=1}^{J} \phi_j(x_{j,k}, u_{j,k}, p_k) \right] \\
\text{s.t.} \quad x_{k+1} = Ax_k + Bu_k + Ed_k, \\
\quad y_k = Cx_k, \\
\quad y_k^{\text{min}} \leq y_k \leq y_k^{\text{max}}, \\
\quad u_k^{\text{min}} \leq u_k \leq u_k^{\text{max}}
\]

---

**Deviation minimisation**

\[
\min \Delta \lambda_{TSO}^T \sum_{t=1}^{\tau} U_t \\
\text{s.t.} \quad \sum_{t=1}^{\tau} \Delta \lambda_{TSO}^T = 0 \\
|\Delta \lambda_{TSO}^T| \leq U_t \quad \forall t \\
|\Delta \lambda_{TSO}^T - \Delta \lambda_{TSO'}^T| \leq \epsilon \Delta \lambda_{TSO'}^T \\
U_t \geq 0 \quad \forall t
\]

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System operators

Communication link

Additional services

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**Motivations**

- Literature
  - CITIES (a Danish Research project, 2014-2020)
  - SmartNet (an EU project, 2016-2019)

**Conclusions**

- Adoption of the CB approach using IC method provides several advantages, as listed below:
  - Suitable for Real-World Applications
  - Additional services
  - Advanced bidding mechanism for the CB approach

**Literature**

- Formulation of MPC is provided in Eq. 1

**Figures**

- Figure 4: Correlation between Price and Consumption from the North West Project Data on March 23,
- Figure 5: Correlation between Price and Consumption from the North West Project Data on March 23,
- Figure 6: Correlation between Price and Consumption from the North West Project Data on March 23,
AS4.0: Summary

AS4.0 is able to solve all the problems in one set, taking into account **stochasticity**, **non linearity** and **dynamics**.

It exploits the **potential** of the flexible resources at the prosumers’ level of **any size**. Also, being based on indirect controls, it is **fast** and fully **automated** at different levels.
Estimating the available flexibility
Aggregated price response

How can we estimate the consumers’ behaviour at the TSO level?
Estimating the available flexibility
Aggregated price response

How can we estimate the consumers’ behaviour at the TSO level?

We assume to deal with consumers that are equipped with energy management systems.

Their response is statistically modelled, knowing:

- The composition of the aggregated pool of consumers.
- The aggregated measurements for each load category.

We approach a cost minimisation, evaluating the perspective of the consumers.

\[
\min_{L_{t,j}} \sum_{t=1}^{\tau} \left( \lambda_{t,j}^{\text{base}} + \Delta \lambda_{t,j}^u + \Delta \lambda_{t,j}^d \right) \sum_{j=1}^{J} \left( L_{t,j}^{\text{base}} + L_{t,j}^d - L_{t,j}^u \right)
\]

subject to:

- \(-r_{t,j}^{\alpha} \leq L_{t,j+1}^{\alpha} - L_{t,j}^{\alpha} \leq r_{t,j}^{\alpha} \quad \forall t, j\)
- \(0 \leq L_{t,j}^d \leq u_{t,j}^d (L_{t,j}^{\text{max}} - L_{t,j}^{\text{base}}) a_{t,j}^d \quad \forall t, j\)
- \(0 \leq L_{t,j}^u \leq u_{t,j}^u (L_{t,j}^{\text{base}} - L_{t,j}^{\text{min}}) a_{t,j}^u \quad \forall t, j\)
- \(\sum_{t=1}^{\tau} (L_{t,j}^d - L_{t,j}^u) = 0 \quad \forall j\)
- \(u_{t,j}^d + u_{t,j}^u \leq 1 \quad \forall t, j\)
- \(y_{t,j}^\alpha - z_{t,j}^\alpha = u_{t,j}^\alpha - u_{t,j-1}^\alpha \quad \forall t, j\)
- \(y_{t,j}^\alpha + z_{t,j}^\alpha \leq 1 \quad \forall t, j\)
- \(\sum_{t=1}^{\tau} y_{t,j}^\alpha \leq n_{j}^\alpha \quad \forall j\)
- \(t' = t + d_j^\alpha \quad \forall t' \in \Psi, j\)
- \(t' = t + d_j^\alpha \quad \forall t' \in \Psi, j\)
- \(t' \in \Psi, t' : \left( (t + d_j^d < \tau) \cap (t + d_j^u < \tau) \right)\)
Conclusions

We present **AS4.0**, a one-way communication approach which exploits controls to handle the ancillary services provision in smart grids. Such an approach is presented together with the existing **alternatives**, including **P2P**, **transactive energy** and the **control-based approach**.

This new method potentially satisfies the various **requirements** of the grid with high penetration of RES, handling stochasticity, non-linearity and dynamics in a fast and simple manner.

We also present an approach for the **estimation of the available flexibility** achievable from consumers at the transmission system level. This is possible by exploiting aggregated measurements for different categories of loads.

In the future, the higher penetration of **energy management systems** will facilitate to get a fast reaction from the consumers to different price signals.
Future work

- Modelling the interaction of DSO and TSO under the AS4.0 mechanism
- Handling the possible conflicts of interest
- Implementing a model to derive time-varying retail prices

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Thank you!