Modelling real-time markets: market design for provision of ancillary services from DER for different TSO-DSO coordination schemes

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For the market simulation, the following *services* procured by the TSO/DSOs are considered and are *procured together*

- **Balancing** services

Forecasted **imbalance** = +100 MW
For the market simulation, the following services procured by the TSO/DSOs are considered and are procured together:

- **Balancing** services
- **Congestion** management
  - At the transmission grid level

**Forecasted congested transmission line**

- **Transmission grid**
  - High Voltage
  - Medium Voltage
  - Distribution grid 1
  - Distribution grid 2

**Distribution grid 2**
For the market simulation, the following **services** procured by the **TSO/DSOs** are considered and are **procured together**

- **Balancing** services
- **Congestion** management
  - At the **transmission** grid level
  - At the **distribution** grid level (medium voltage)
For the market simulation, the following services procured by the TSO/DSOs are considered and are procured together:

- **Balancing services**
- **Congestion management**
  - At the transmission grid level
  - At the distribution grid level (medium voltage)

- In addition, the goal is also to avoid creating voltage problems in the distribution grid (medium voltage)

⇒ Requirement for transmission and distribution grid models in the market clearing algorithm

Avoid under or overvoltages when providing the services.
Market design specificities for different TSO-DSO coordination schemes

<table>
<thead>
<tr>
<th>Centralized</th>
<th>Decentralized</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Centralized AS market</td>
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</tbody>
</table>

- **Transmission grid** model only
- **Congestion** management DSO level is tackled outside market

TSO-DSO Coordination Schemes

Centralized AS market

- High Voltage
- Medium Voltage

Distribution grid 1

Distribution grid 2
Market design specificities for different TSO-DSO coordination schemes

TSO-DSO Coordination Schemes
- Centralized
  - Centralized AS market
  - Common TSO-DSO AS market (centralized)
- Decentralized

Common TSO-DSO AS market (centralized)

- Transmission + distribution grid models
- Minimize total activation costs for TSO and DSOs
Market design specificities for different TSO-DSO coordination schemes

TSO-DSO Coordination Schemes

Centralized
- Centralized AS market
- Common TSO-DSO AS market (centralized)
- Integrated flexibility market

Decentralized

• Transmission + distribution grid models
• Maximize welfare
• CMPs (e.g. BRP) allowed to purchase flexibility offers on the market, in competition with SO
  ➔ TSOs, DSOs need to explicitly bid on the AS market

Integrated flexibility market

High Voltage

Medium Voltage

Transmission + distribution grid
Maximize welfare

CMPs (e.g. BRP) allowed to purchase flexibility offers on the market, in competition with SO

TSOs, DSOs need to explicitly bid on the AS market
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**Decentralized**
- Local AS market

**TSO-DSO Coordination Schemes**

- **DSO** uses **local market** as a priority to solve local problems (**congestion**)
- Then **remaining flexibility** is (smartly) **aggregated** and sent to the **TSO AS market**
Market design specificities for different TSO-DSO coordination schemes

TSO-DSO Coordination Schemes

Centralized
• Centralized AS market
• Common TSO-DSO AS market (centralized)
• Integrated flexibility market

Decentralized
• Local AS market
• Common TSO-DSO AS market (decentralized)

• **DSO** is responsible to collect bids from DER on a local market and to *(smartly) aggregate* them and send them on TSO market

• **Smart aggregation**
  – Take *distribution grid* constraints into account
  – Solve *DSO problems* (congestion) for any quantity proposed in the bid

Common TSO-DSO AS market (decentralized)
Market design specificities for different TSO-DSO coordination schemes

**Centralized**
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- Integrated flexibility market

**Decentralized**
- Local AS market
- Common TSO-DSO AS market (decentralized)
- Shared balancing responsibility model

- **DSO** and **TSO** agree in advance on a **power profile exchange** at the HV-MV substation
- Each **market** solves its balancing and congestion problems using its own resources
Key market design ingredients

<table>
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<th>Dimension</th>
<th>Question</th>
</tr>
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<tbody>
<tr>
<td>Network</td>
<td>Which <strong>mathematical models</strong> for the distribution and transmission grids in the market clearing algorithm?</td>
</tr>
<tr>
<td>Timing</td>
<td>What are the market clearing <strong>frequency</strong>, time <strong>granularity</strong> and <strong>horizon</strong>?</td>
</tr>
<tr>
<td>Bidding</td>
<td>How market actors can bid? What market products are proposed?</td>
</tr>
<tr>
<td>Clearing</td>
<td>What are the objectives of the market clearing?</td>
</tr>
<tr>
<td>Pricing</td>
<td>What price is paid to the activated bids?</td>
</tr>
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Use of different models for the transmission and distribution grids

Transmission grid

MV distribution grid

SOCP Problem (Convex optimization problem)

1 Photo source: Technical University of Munich (http://ens.ei.tum.de)
The market is a closed-gate auction.

Generic approach to test combinations of important timing parameters

- **Time horizon** of the market (optimisation window, delivery period): e.g. 30 min
- **Time granularity** of the market horizon: e.g. 5 min
- **Market clearing frequency**: e.g. 30 min
  - The shorter, the better, but limited by optimization problem complexity (market clearing duration)
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### Generic approach to test combinations of important timing parameters

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- **Rolling optimisation concept** when time horizon larger than market clearing frequency AND time granularity:
  - e.g. horizon = 30 min, frequency = 5 min, granularity = 5 min
  - Results for the **first time step are a firm decision.** It contains the actual activation of flexible assets and has to be followed by the aggregators/owners
  - Results for the **next time steps are (mostly) advisory decisions.** They will assist the aggregators and the TSO to anticipate the availability of flexibility in the upcoming time steps.

The market is a **closed-gate auction.**
A catalogue of **market products** is proposed, to allow all flexibility providers to be on a **level playing field**

- **Bids** are energy offers/asks, defined by **quantity/price** pairs in their simplest form
- **Curtailable** or non-curtailable
- Extension to **multi-period bids** when time horizon is larger than the time granularity
- **Complex** constraints
  - **Temporal** constraints
  - **Logical** constraints
- **Binary variables** are needed to express some of these constraints (e.g. a simple non-curtailable bid requires a binary variable)

→ **MISOPC Optimisation** problem

- **Temporal constraints** (Intra-bid)
  - Accept-All-Time-Steps-or-None: → Profile tracking
  - Ramping: → Turbines
  - Max. number of activations: → Avoiding wear & tear
  - Max. duration of activation: → Air conditioning
  - Min. duration of activation: → Plant efficiency
  - Min. delay between activations: → Avoiding wear & tear; cool-down and warm-up
- **Integral**: → Electric storage

- **Logical constraints** (Inter-bid)
  - Implication: → Series factory lines
  - Exclusive Choice: → Parallel factory lines
  - Deferability: → Wet appliances
Optimization **objective** under **network** and **bid constraints**

- Minimize activation costs and maximizing welfare may return different results

- Objective is to **minimize the activation costs** in all coord. Schemes, **except** for the integrated flexibility market TSO-DSO CS

- Maximizing social welfare for the latest, since regulated and non-regulated entities are in competition for the same flexibility resources
Locational marginal price (LMP) chosen to remunerate bidders

- Potentially different prices for each network node (in the model), due to:
  - Losses
  - Congestions

- Pros: Projects real value of flexibility at each node
- Cons: Complex pricing mechanism and intuitiveness
A part of the **computational tractability** of the market clearing algorithm depends on the design choices...

- **SOCP network model for distribution grid**
  - more accurate model BUT **computationally more challenging** than linear model
  - **Tractability** also depends on the **size of network** to handle

- Introducing **binary variables complicates a lot** the optimisation problem (**MISOCP**), but needed for many market products (e.g. a simple non-curtailable bid)
  - Need to limit and/or make sure not too many binary variables are introduced (i.e. make sure it is worth to have them)

- A time horizon with **multiple time steps** may be advantageous but also **introduces further computational complexity** (e.g. bids with inter-temporal constraints)
... another part of the computational tractability depends on the TSO-DSO coordination scheme

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<th>Shared balancing responsibility model</th>
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<td>The easiest since only transmission grid</td>
<td>The most difficult since full transmission AND distribution grids in a single problem</td>
<td>Optimizations in parallel BUT with smart aggregation using some complexity</td>
<td></td>
<td>Many optimizations in parallel</td>
<td></td>
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Computational tractability linked to TSO-DSO coordination scheme mainly depends on whether they are centralized or decentralized

- direct impact on the network dimension to tackle in the optimisation problem
- Quite challenging to solve the coord. schemes with full networks included (transmission grid + multiple distribution grids)
  - Ongoing work on spatial (network) decomposition methods to efficiently solve such problems
Challenges and next steps

• Your feedback is welcome: preliminary report on market design and algorithm (Deliverable D2.4) available on SmartNet website

  http://smartnet-project.eu/

• Run the algorithms on real data instances form simulated scenarios (Denmark, Italy, Spain) to compare the different TSO-DSO coordination schemes

• Computational Tractability issues: solving a MISOCP (market clearing) in a few minutes is challenging → investigation of efficient methods to tackle this issue

• Data availability: e.g. prediction of injection/offtake at network nodes, scheduled TSO-DSO exchange profiles
This presentation reflects only the author’s view and the Innovation and Networks Executive Agency (INEA) is not responsible for any use that may be made of the information it contains.
Thank You

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