SmartNet

Smart TSO-DSO interactions schemes, market architectures and ICT solutions for the integration of ancillary services from demand side management and distributed generation

SmartNet workshop series

Florence, October 24th – 26th 2018

Market and aggregation structure

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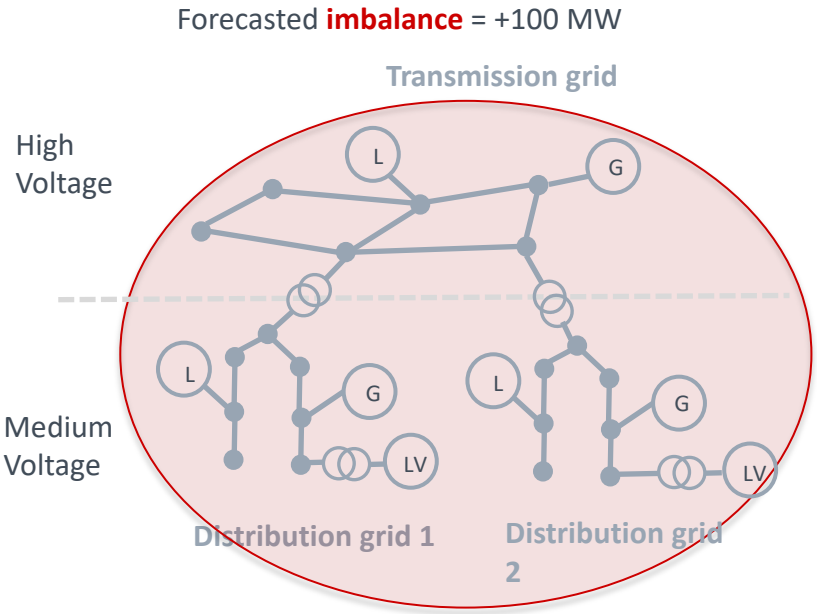
Outline

- SmartNet AS **market scope**
- **Aggregation** specificities
- **Market specificities**

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

- **Balancing** services



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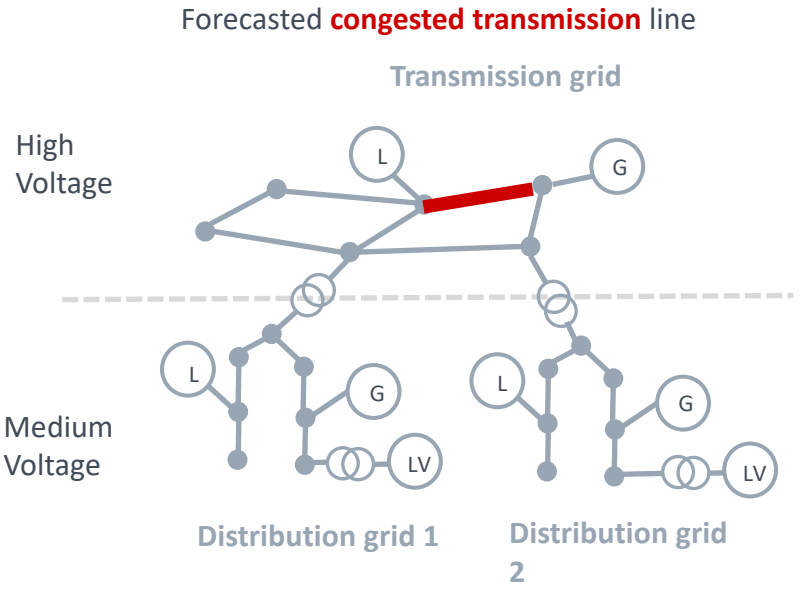
- **Congestion** management
  - At the **transmission** grid level



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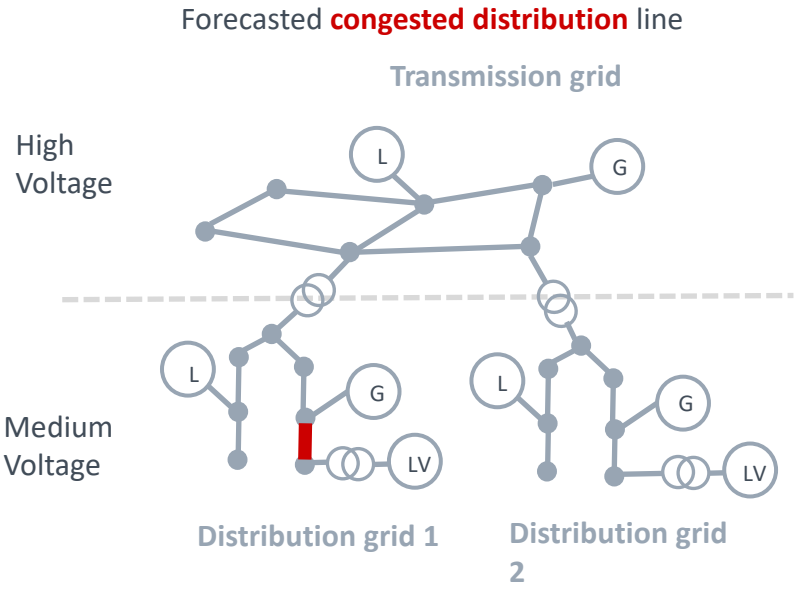
  - At the **distribution** grid level (medium voltage)



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

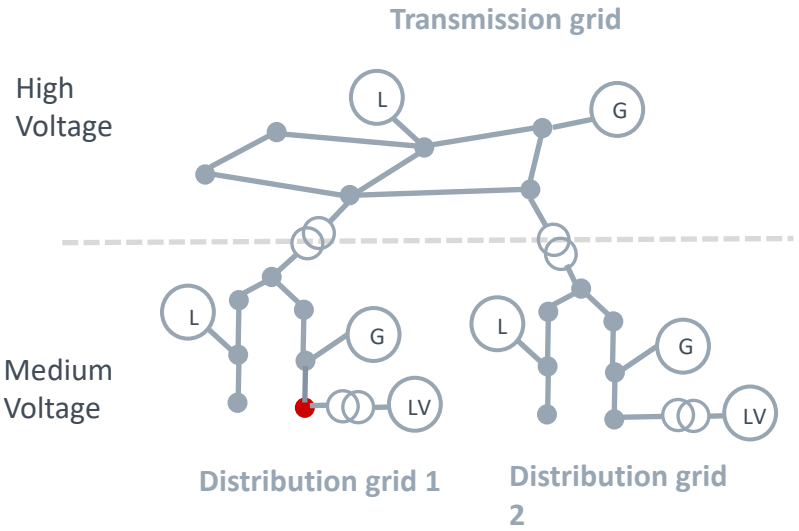
- **Balancing** services
- **Congestion** management
  - At the **transmission** grid level
  - At the **distribution** grid level (medium voltage)

- 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**

➔ Need for **network observability** and ability to **forecast** the near future network state

Avoid **under** or **overvoltages** when providing the services



SmartNet market deals with procurement/activation of the **energy**, **not reserves**

- SmartNet market algorithm **does not cope** **with the** **reserve dimensioning** **and** **procurement**, although also relevant to study.

- In the RIA SmartNet, we are **not tied to a particular product** (e.g. aFRR, mFRR), but the services would typically :
  - **Encompass mFRR/RR** products **time frame**
  - **Not encompass aFRR** (update of setpoint every few seconds) or **FCR** (local controller) time frame DUE to timing reasons

Outline

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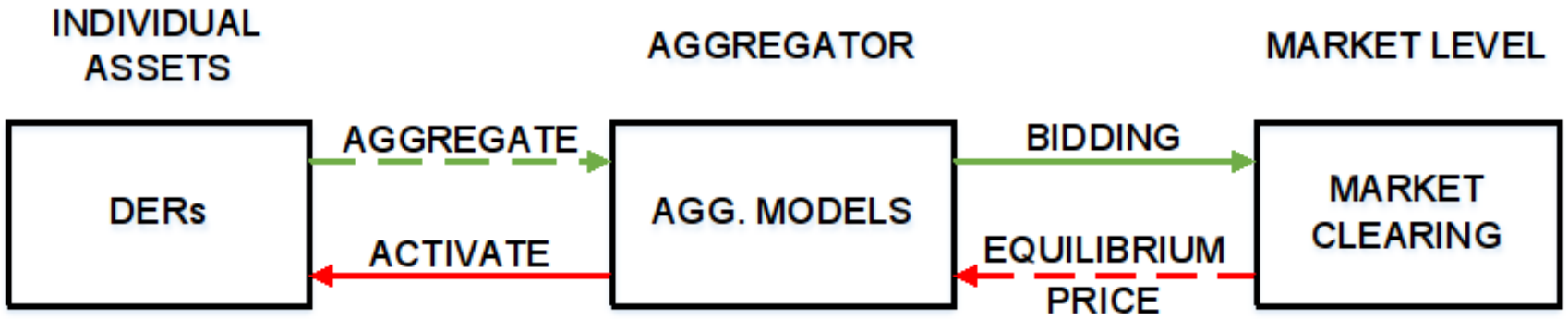
- **Aggregation** specificities
- **Market specificities**

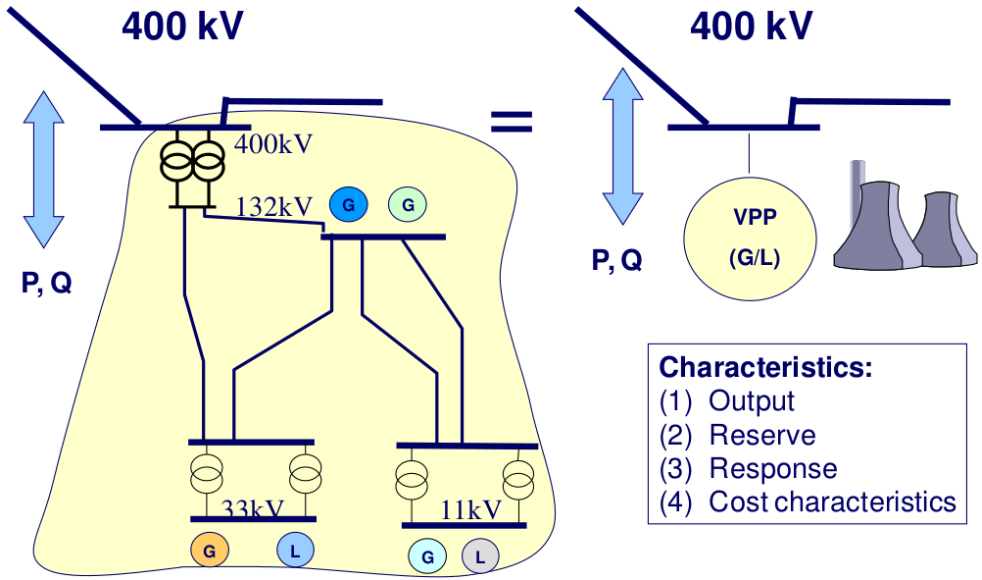
Aggregator's role



- visibility to MO (≥ 100 kW)
- filters necessary data to MO
- balance responsibility
- activation

MO – market operator

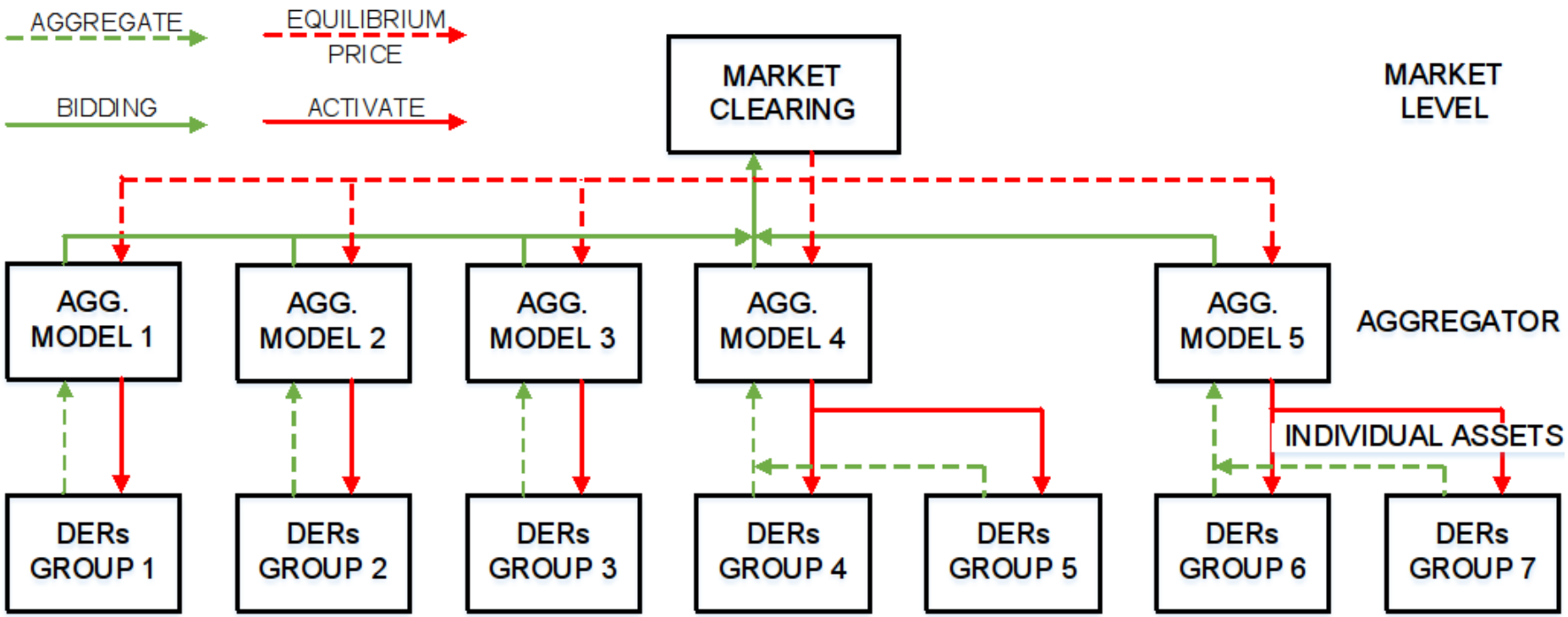
FENIX (10/2005 – 09/2009)



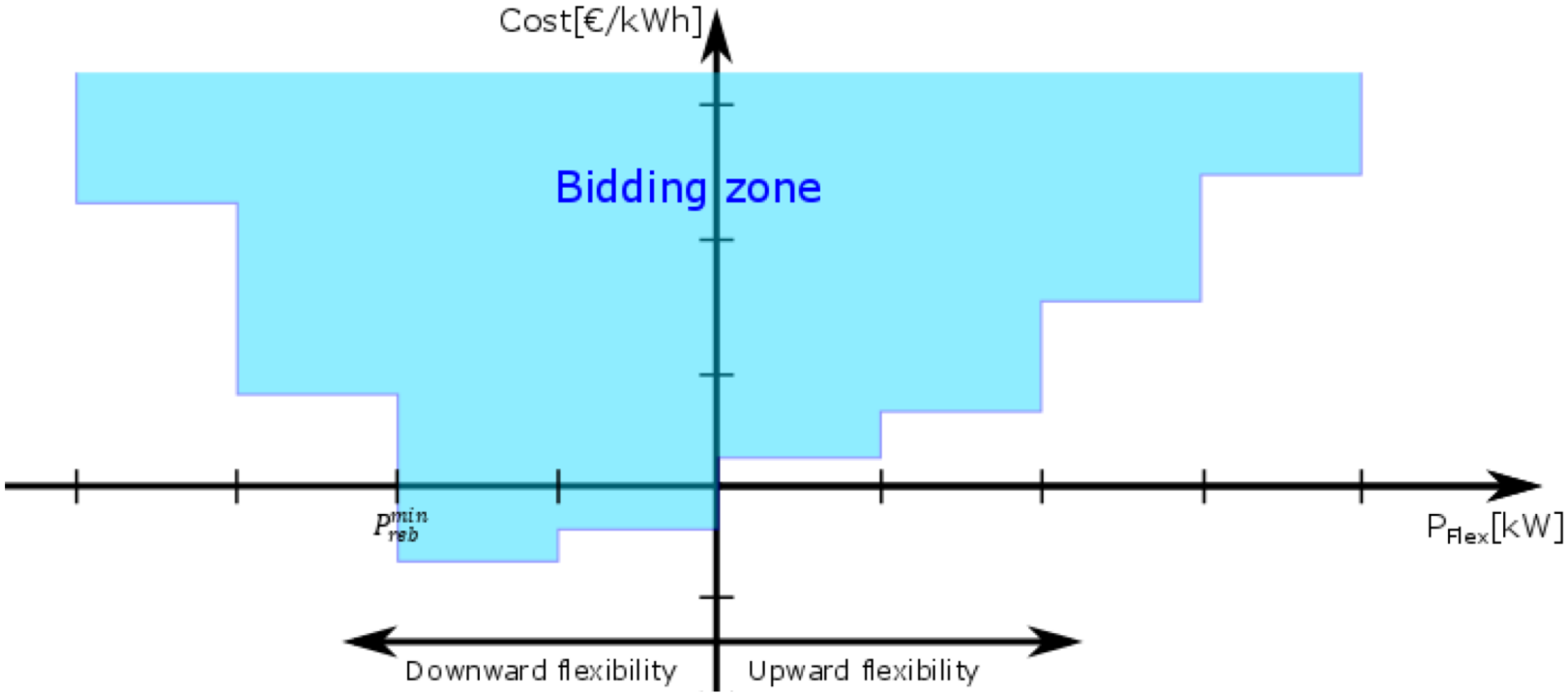
- single aggregation model
- physical approach
- agg. DERs @ trans. – distr. interface, concept of VPP
- D. Pudijanto et al., ”VPP and system integration of DERs”

VPP – virtual power plant

SmartNet aggregation models

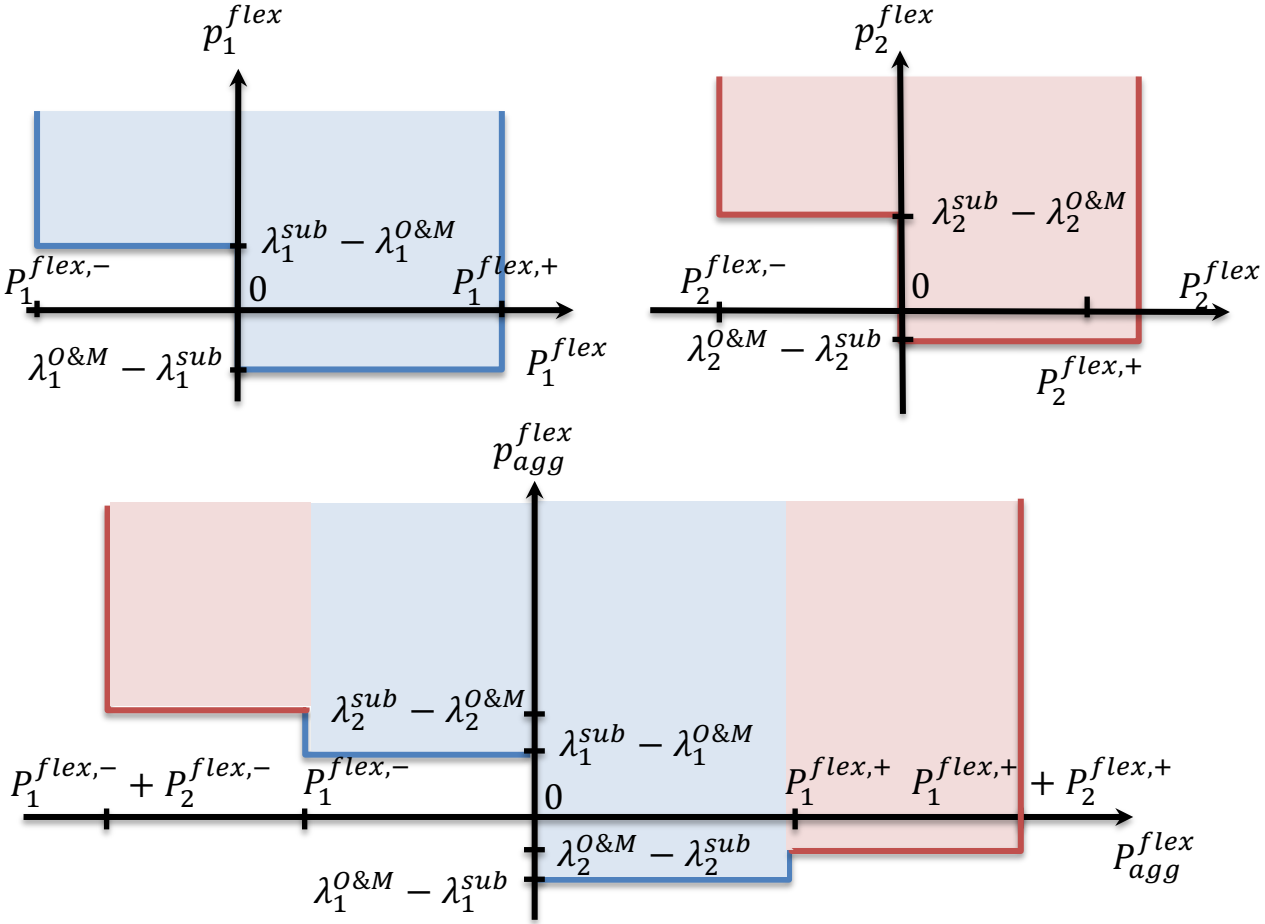


AGG. MODEL 2 bid curve (CHP units)

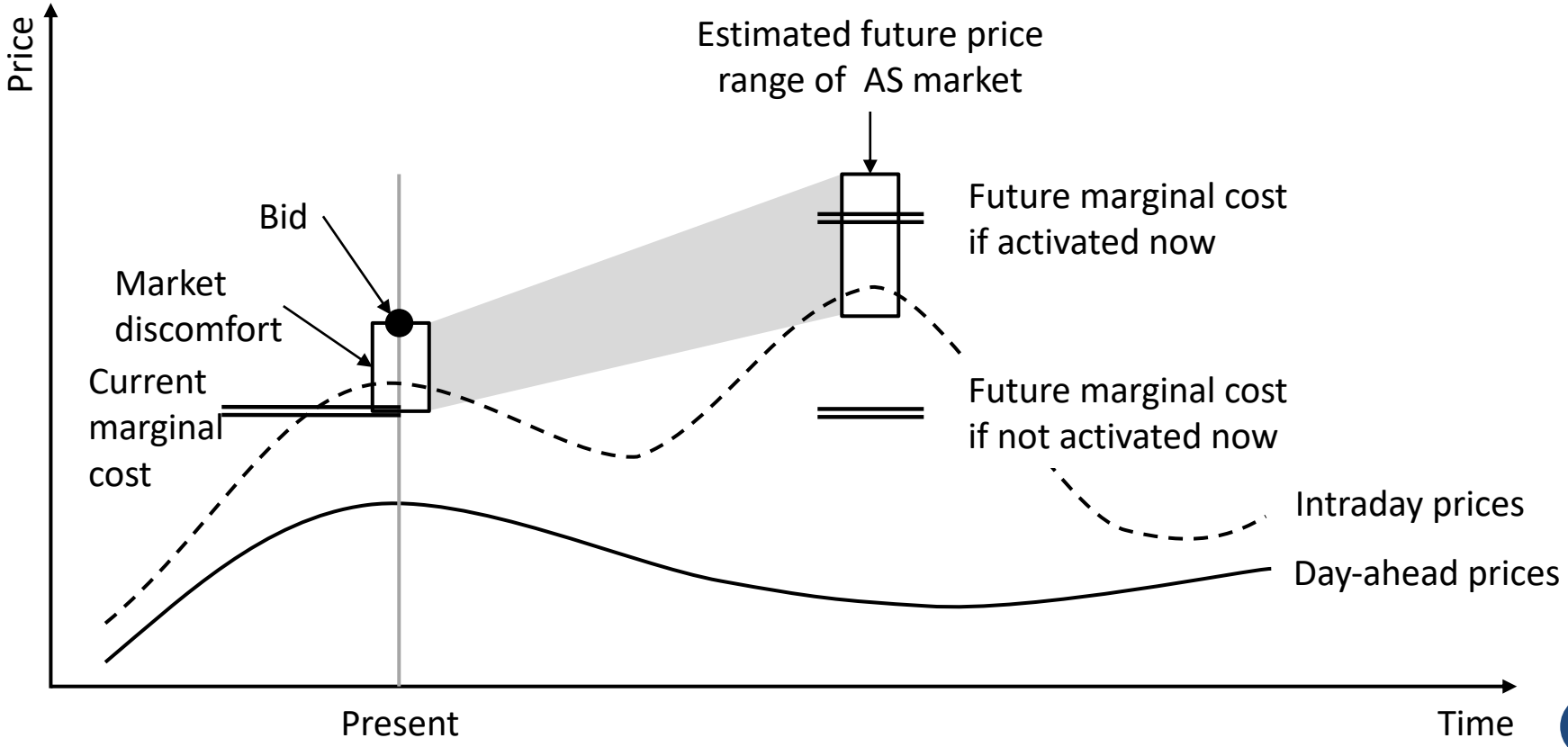


- zero power corresponds to baseline

AGG. MODEL 5 bid curve (curt. gen.)



Market discomfort cost (*source: ONE*)



Outline

- SmartNet AS **market scope**
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- **Market specificities**

Key **market design ingredients**

Network Dimension

Which **mathematical models** for the distribution and transmission grids in the market clearing algorithm ?

Timing Dimension

What are the the market clearing **frequency** (e.g. every hour), time **granularity** (e.g. 15min)**, horizon** (e.g. 1 hour), **Gate closure time** (e.g. 15min before real-time) ?

Bidding Dimension

- A catalogue of market products is proposed, from **simple** to **complex** bids (**logical** constraints, inter-temporal constraints).
- **Bidding** is done **at nodal level**

Clearing Dimension

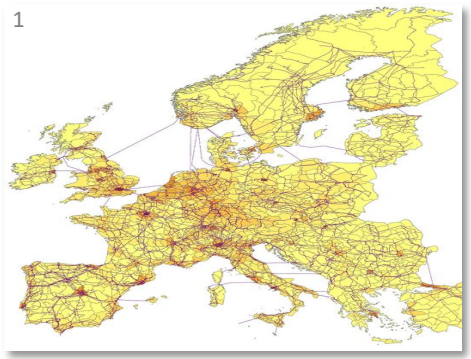
What are the objectives of the market clearing ? **Minimize activation cost** (avoiding unnecessary activations)

Pricing Dimension

- **Pay-as-clear** chosen over pay-as-bid
- **Nodal pricing** chosen, to reflect better the value of flexibility

Which **network models** for the **transmission** and **distribution** grids?

Transmission grid



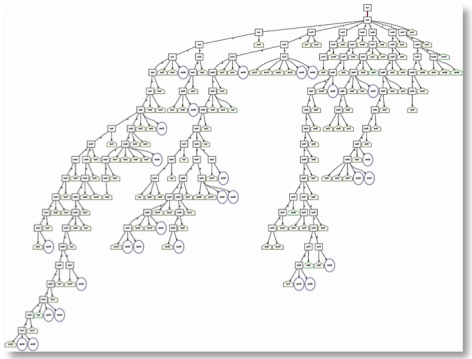
+ Accuracy

+ Numerical Complexity

Copper plate — LP — AC (NLP)

+

MV **distribution** grid



+ Accuracy

+ Numerical Complexity

Coppe r plate — LP — SOCP — AC (NLP)

Need to choose **convex approximation/relaxations** of the network models to make them **computationally tractable** in a **market clearing optimization** algorithm since **binary variables** are also part of the problem.

[1] Photo source: Technical University of Munich (*http://ens.ei.tum.de*)

Market design specificities for different TSO-DSO coordination schemes

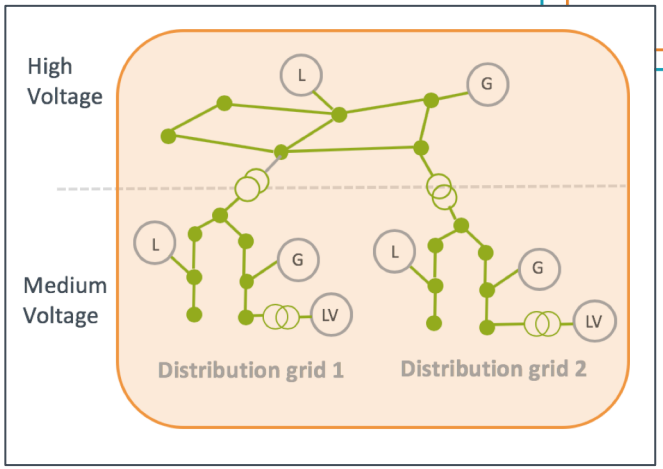
TSO-DSO Coordination Schemes

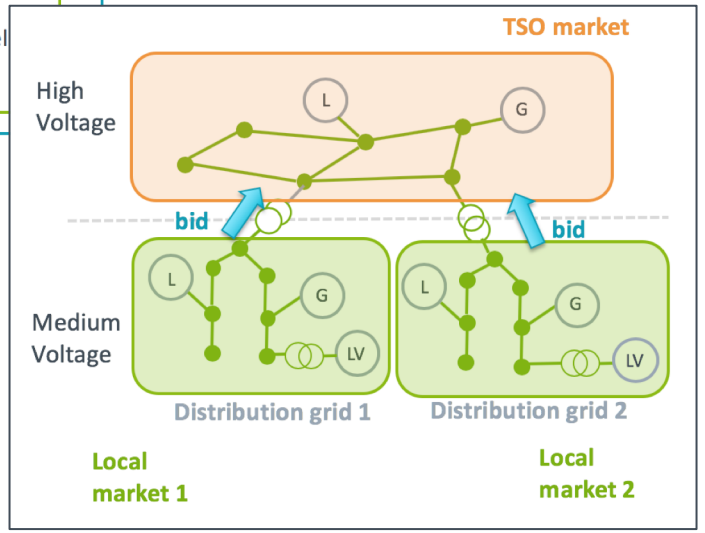
Centralized

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

Decentralized

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





A part of the **computational tractability** of the **market clearing algorithm depends on** the intrinsic **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

Italian scenario = one 4000 nodes HV Transmission grid + **700 MV distribution grids** for a total of **about 10 000 nodes**)

- 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**

Centralized AS market	Common TSO-DSO AS market (centralized)	Integrated flexibility market	Local AS market	Common TSO-DSO AS market (decentralized)	Shared balancing responsibility model
The **easiest** since only transmission grid	The **most difficult** since full transmission AND distribution grids in a single problem		Optimizations in parallel BUT with smart aggregation using some complexity		Many optimizations in parallel

Computational tractability linked to TSO-DSO coordination scheme mainly **depends on** whether they are **centralized** or **decentralized**

➔ direct impact of the **network dimension** to tackle on the **optimisation** problem

➔ Quite challenging to solve the coord. schemes with full networks included (**transmission grid + multiple distribution grids**)

SmartNet

SmartNet-Project.eu

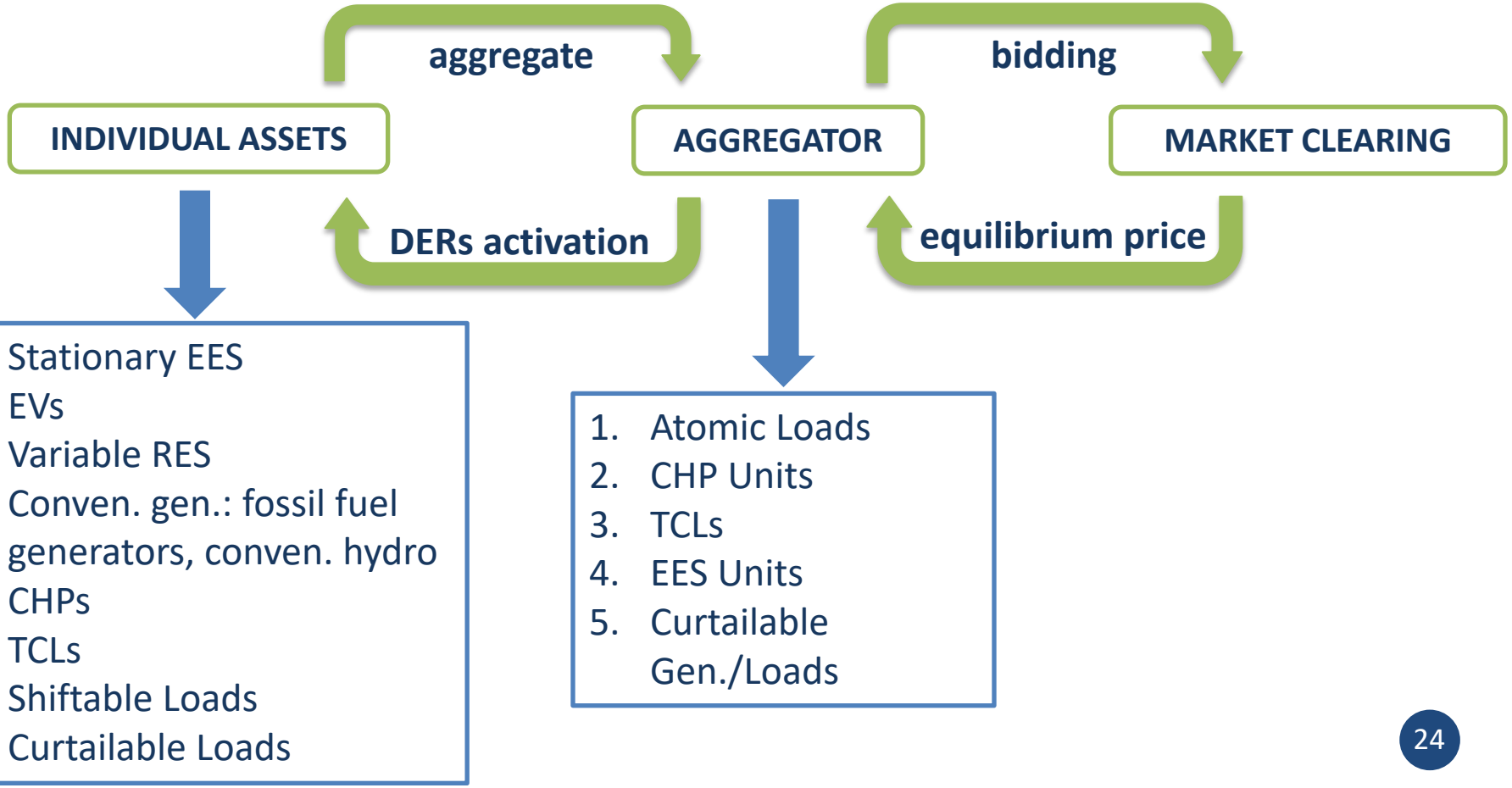
Backup slides – not for diffusion

ADDRESS (06/2008 – 05/2013)

SmartNet

- aggregating household devices
- clusters of consumers
- aggregator max. revenue, sends price-volume signal to cluster
- cluster minimizes end-users' electricity bill
- access day-ahead and intraday markets
- P. Koponen et al., "Toolbox for Aggregator of Flexible Demand"

SmartNet aggregation models (1)



SmartNet aggregation models (2)

Model	Aggregation approach
CHP Units	Physical
Curtailable generation and curtailable loads	
EES Units	
TCLs	
Atomic Loads	Traces

- **Traces approach**

  Characterized by load profiles and the cost associated to each profile, and not by the exact physical DERs' characteristics.

  ✔ The disaggregation is straightforward.

- **Physical (bottom-up) approach**

  The aggregator knows all parameters of DERs and its real time status.

  ✔ The disaggregation is straightforward.

  ✖ Potentially hard to implement when many heterogeneous energy resources are included.

Aggregation approaches

Aggregation approaches used for bidding in electricity markets:

- Physical (bottom-up) approach
- Traces approach
- Data driven approach
- Hybrid approach

Each of them has certain advantages: accuracy, required data, disaggregation.

SmartNet aggregation models (3)

1. Atomic Loads
   - Wet appliances – washing machine, washer dryer, dishwasher, tumble dryer.
   - Industrial processes – paper and paperboard, mining and quarrying, etc.
2. Combined Heat and Power Units
3. Thermostatically Controlled Loads
   - HVAC, water and electric heaters.
4. EES Units
   - EVs, Stationary EES.
5. Curtailable Generation and Sheddable Loads
   - Variable RES (Wind, PV and small-scale hydro generation).
   - Curtailable loads without the rebound effect (lighting).

SmartNet aggregation models (4)

Models	Aggregation approach
CHP	Physical
TCL	
Storage	
Curtailable generation and sheddable loads	
Atomic Loads	Traces

- Atomic Loads
  - Wet appliances – washing machine, washer dryer, dishwasher, tumble dryer.
  - Industrial processes – paper and paperboard, mining and quarrying, etc.
- Combined Heat and Power (CHP)
- Thermostatically Controlled Loads (TCLs)
  - HVAC, water and electric heaters.
- Storage
  - Static and mobile battery.
- Curtailable generation and sheddable loads
  - Wind, PV and small-scale hydro generation.
  - Loads that can be shed without rebound effects such as lighting.

Network Dimension

Use of **different models** for the **transmission** and **distribution** grids

Transmission grid

1 model

Traditional **Linear DC approximation**

- **No losses** are modelled
- Voltage angles between neighbours are small
- **No reactive power** notion, **constant voltage** magnitude

MV distribution grid

3 models

1) **SOCP BFM (distflow)** model
   - **Losses** are modelled
   - **Active** and **reactive power** are modelled
   - Exact solution in many realistic cases

   BUT tuning of a penalty term in objective **difficult** to achieve

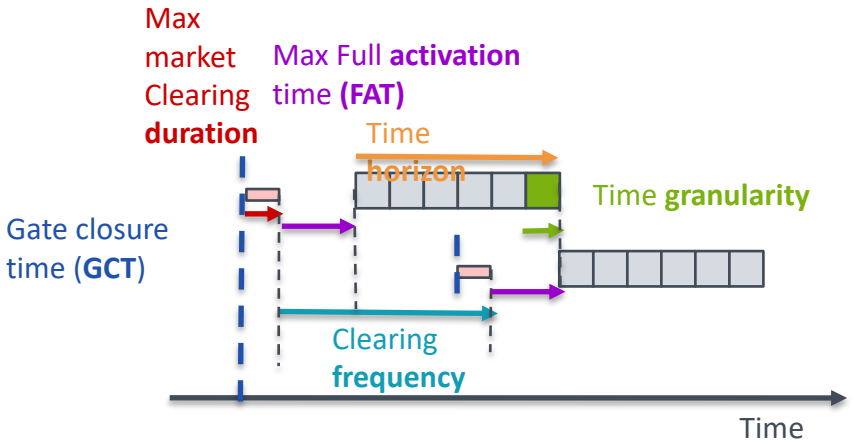
2) **Linear Ben-Tal relaxation** model
   - **Linearize** conic constraints
   - Allows to use efficient MILP warm-start capabilities of (commercial) solvers

3) **Linear Simplified distflow** model
   - **No losses** are modelled
   - Equivalent of DC approximation used at transmission
   - No need to tune penalty term

Generic approach to test **combinations** of important **timing parameters**

The market is a **closed-gate auction**.

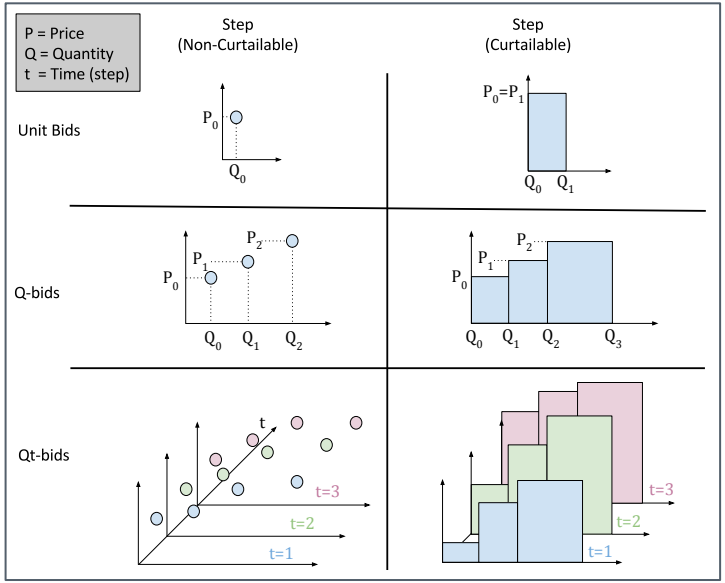
- **Time horizon** of the market (optimisation window, delivery period): e.g. 30 min
- **Time granularity** of the market horizon: e.g. 5 min
- **Market clearing frequency**: e.g. 30 min
  - → The shorter, the better, but limited by optimization problem complexity (market clearing duration)
- **Max Full Activation time (FAT)** of the product: e.g. max 10 min
  - → in SmartNet simulator, we assume 0 min, for sake of simplicity
- **Max clearing time** = Max allowed time for market clearing algorithm to return the decisions: e.g. 5 min
- **Gate closure Time (GCT)** : e.g. 15 min before delivery period starts (10 min FAT + 5 min market time)



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** contraints
  - **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)

➔ **MISOCP/MILP Optimisation** problem



Temporal constraints (Intra-bid)

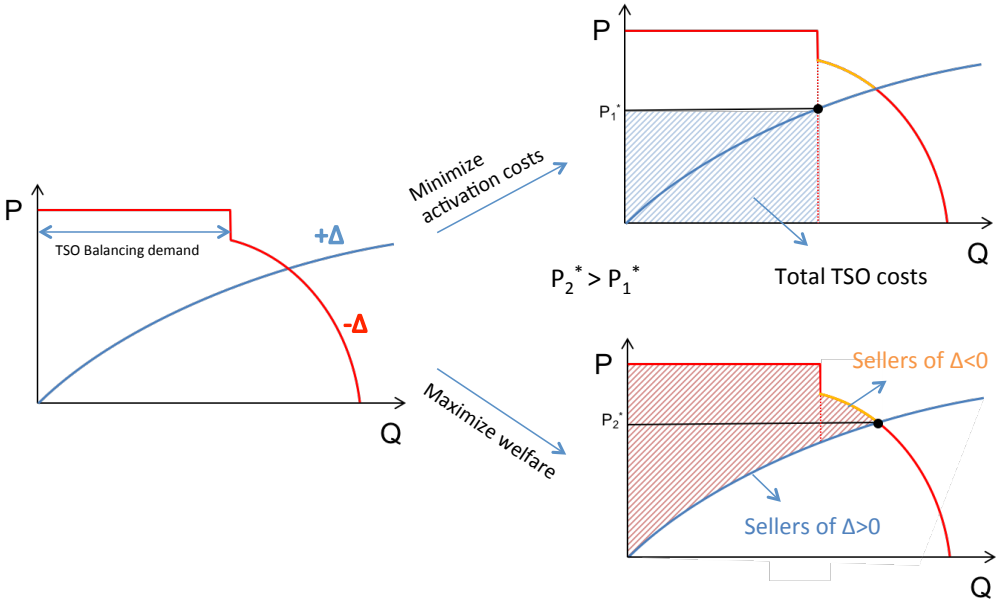
- **Accept-All-Time-Steps-or-None**: → Profile tracking
- **Ramping**: → Turbines
- **Max. number of activations**: → Avoiding wear & tear
- **Max. duration of activation**: → Air conditioning
- **Min. duration of activation**: → Plant efficiency
- **Min. delay between activations**: → Avoiding wear & 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

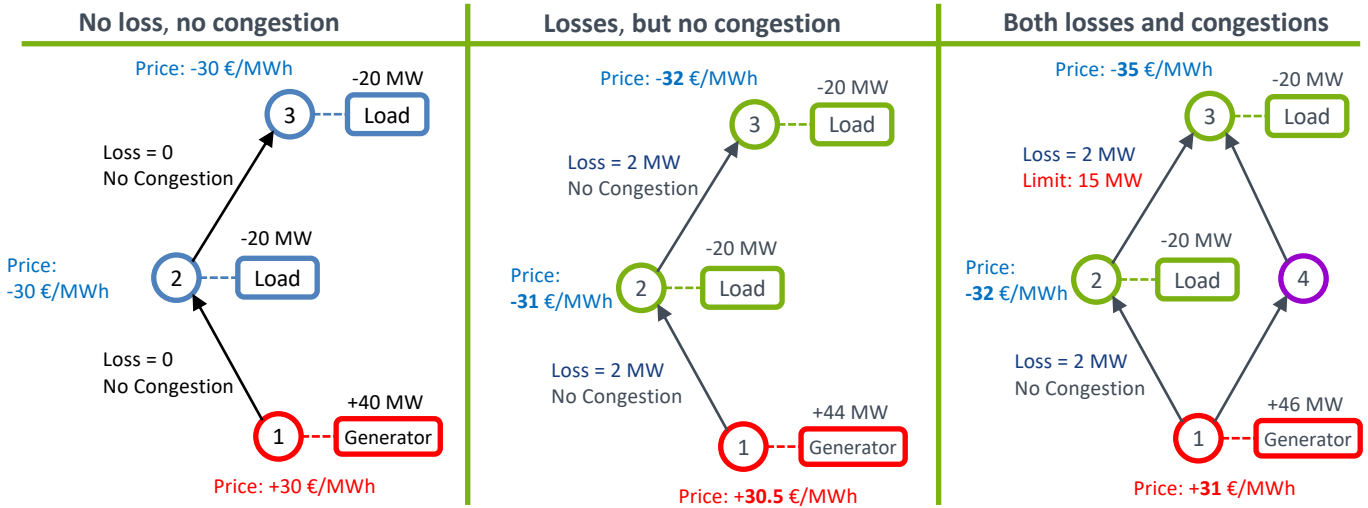
- **Minimize activation costs** and **maximizing welfare** may return different results
- Objective is to **minimize the activation costs** in all coord. Schemes, **except** for the *integrated flexibility market* TSO-DSO Coord. Scheme
- Maximizing social welfare for the latest, since regulated and non-regulated entities are in competition for the same flexibility resources



Locational "Nodal" marginal price (LMP) chosen to remunerate bidders

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

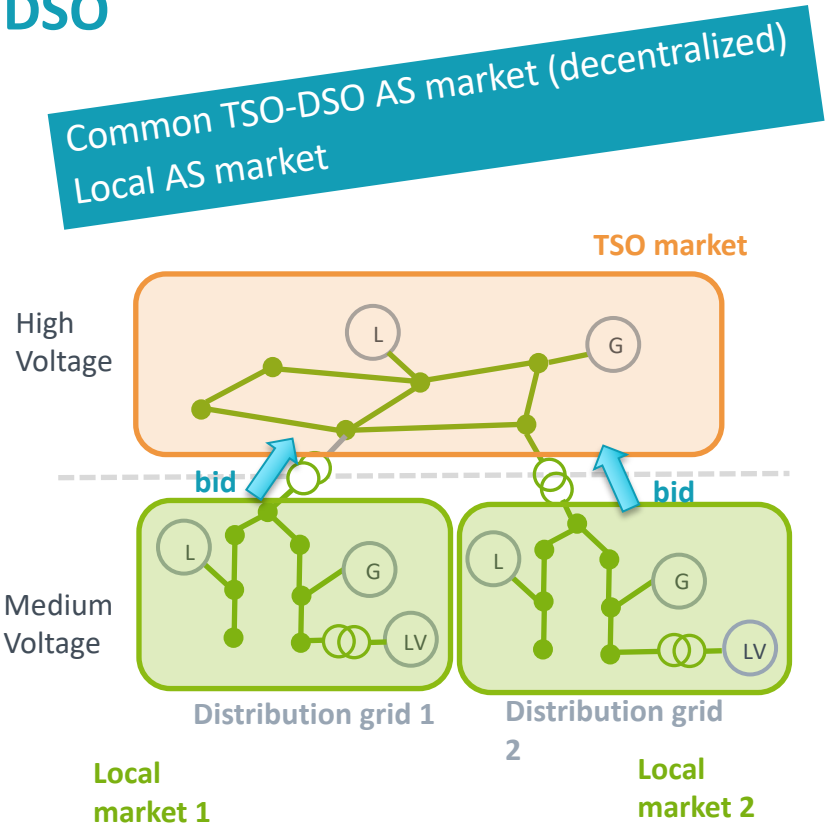
- **Pros**: Projects real value of flexibility at each node
- **Cons**: Complex pricing mechanism and intuitiveness



A bit more on “Smart” aggregation by the DSO

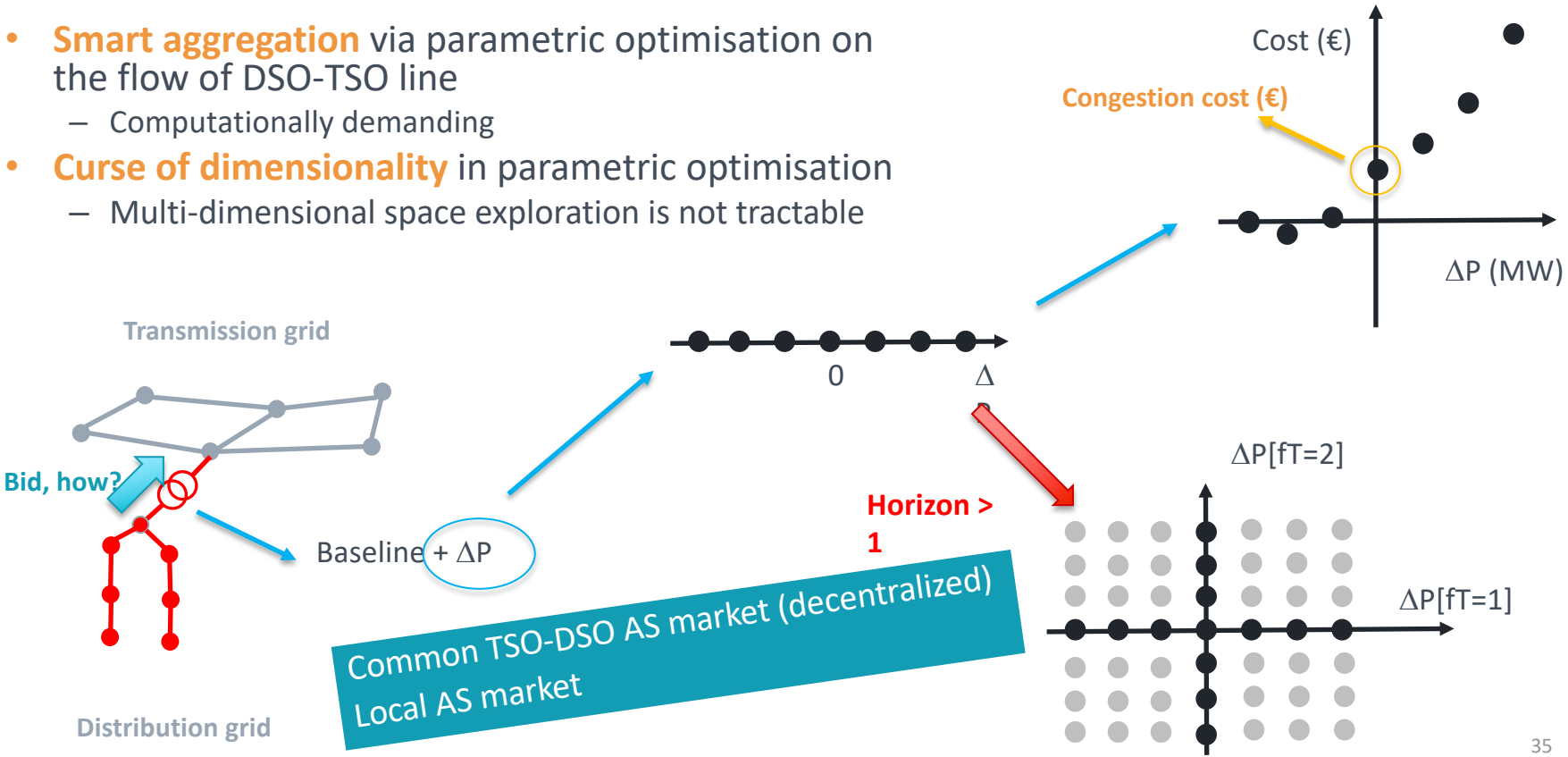
(Remaining) **bids** on **local markets** need to be **transferred** to the **TSO market**

- **Easy solution**:
  - **transmit bids** to the TSO market platform **without** any network constraints check
  - BUT **no guarantee** that distribution grid constraints will be satisfied for the bids activated by TSO
- **Medium solution**:
  - Transmit bids to the TSO market platform, provided they are prequalified according to a simple method.
  - But **how** to do that in a **simple**, **transparent** and **fair** manner?
- **Difficult** but **smart solution:**
  - **Aggregate** bids in local markets according to an **objective** and satisfying **network constraints**



DSO smart aggregation

- **Smart aggregation** via parametric optimisation on the flow of DSO-TSO line
  - Computationally demanding
- **Curse of dimensionality** in parametric optimisation
  - Multi-dimensional space exploration is not tractable



TSO-DSO CS-dependent
Timing Dimension

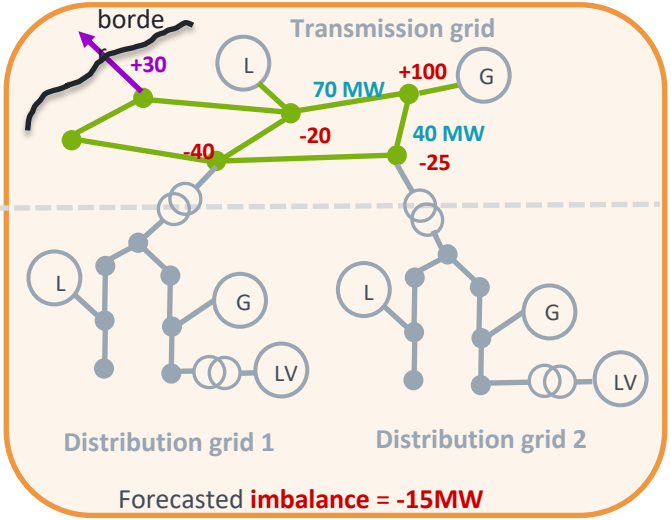
CS A: Centralized AS market

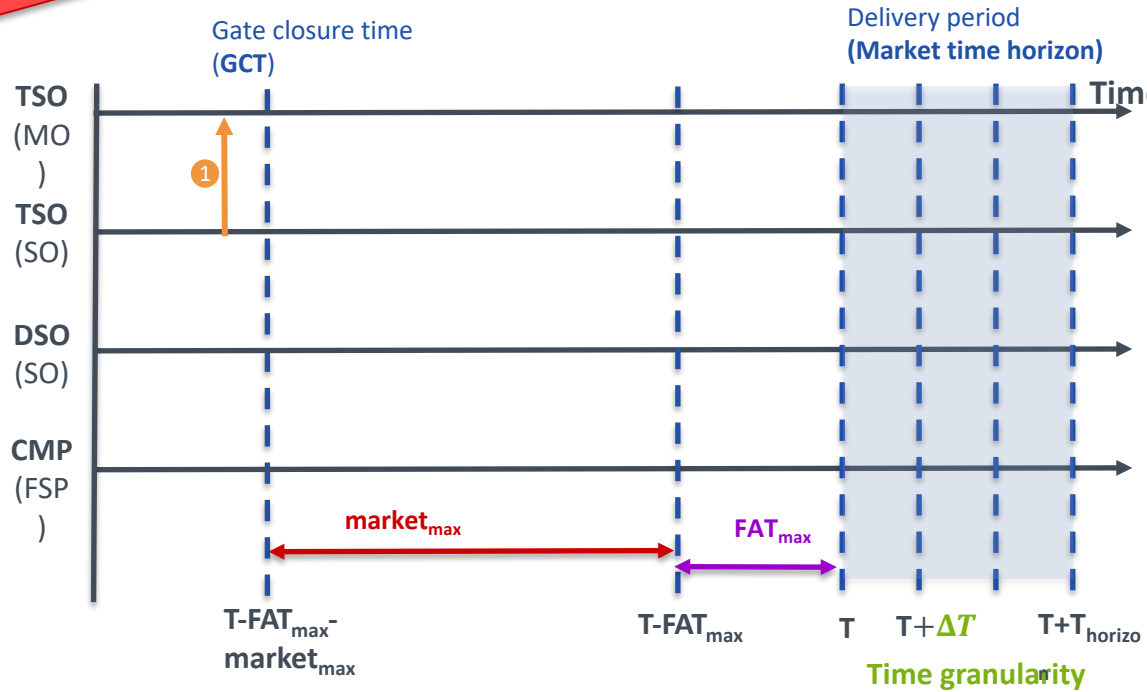
Net power injection at node i =
Sum of power **generated** at node i
- Sum of power **consumed** at node i

Market$_{max}$ = Max time allowed for market algorithm (+pre/post-processing)

FAT$_{max}$ =Max full activation time for the product

1 TSO (SO) sends the **forecasted grid state**, per market time step (granularity), to the market operator before **GCT**:
- Forecasted **net nodal power injection**
- **Operational limits** (if changed)
- **Grid topology** (if changed)
- Scheduled/Agreed Flows at **borders**

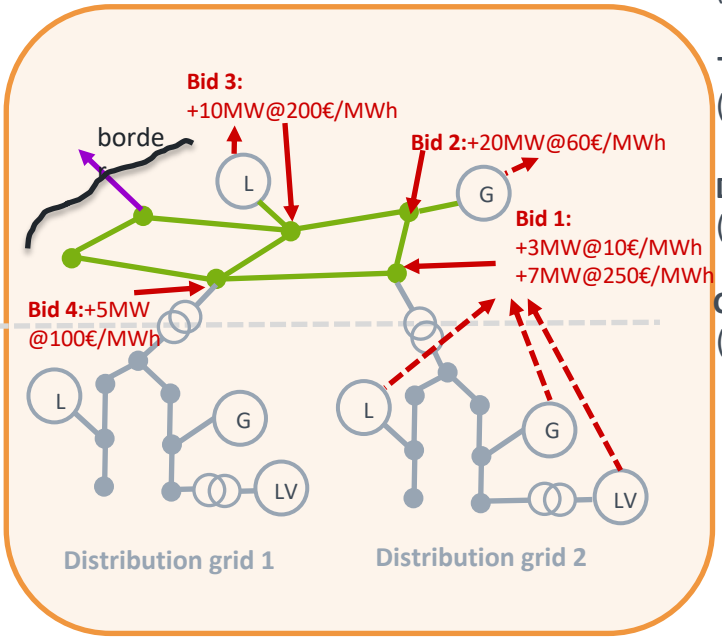




TSO-DSO CS-dependent
Timing Dimension

CS A: Centralized AS market

2 CMP (FSP: **F**lexibility **S**ervice **P**roviders) send **bids** to the MO (TSO), at **transmission grid nodal resolution**



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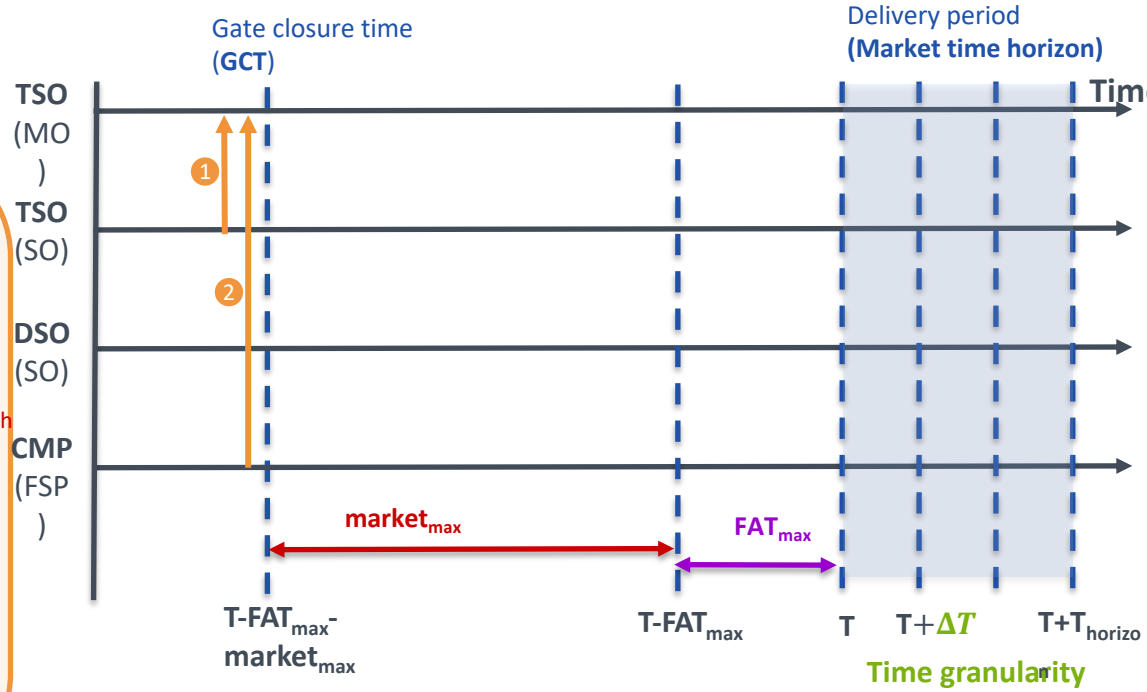
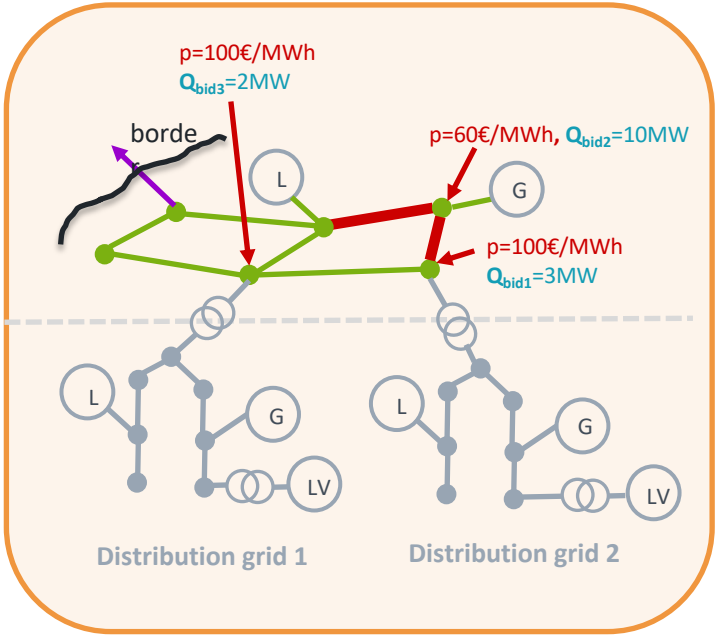


TSO-DSO CS-dependent
Timing Dimension

CS A: Centralized AS market

3 MO **runs** the **market clearing algorithm**: it computes the accepted bid **quantities** and **nodal** marginal **price**.



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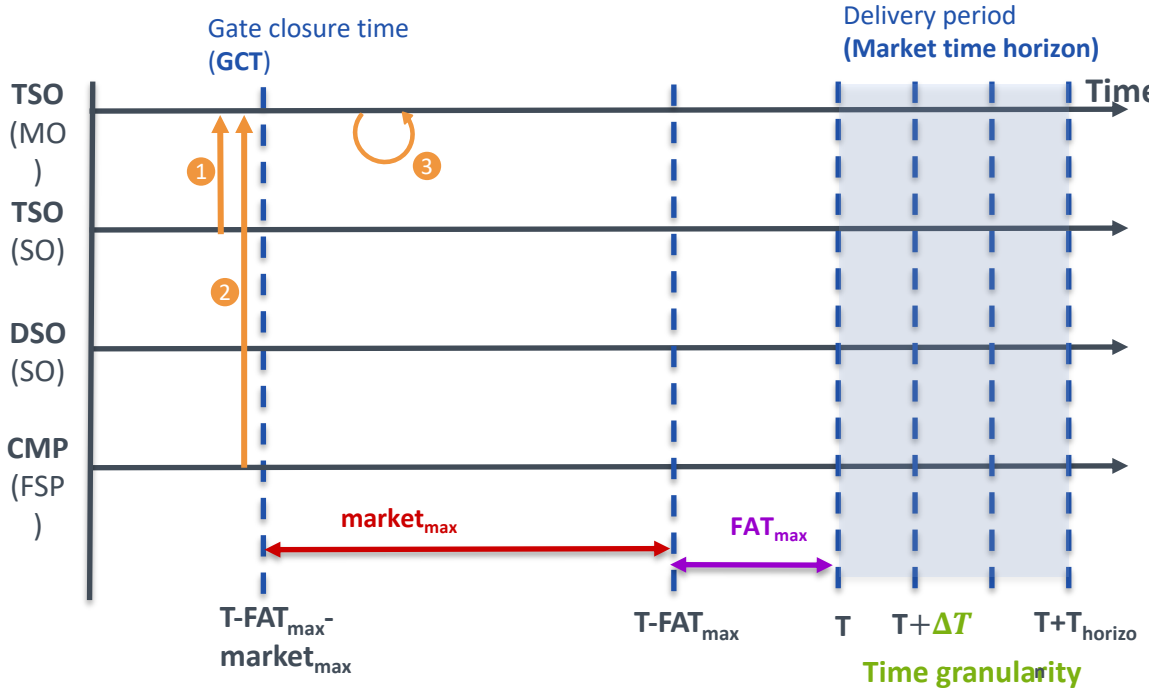
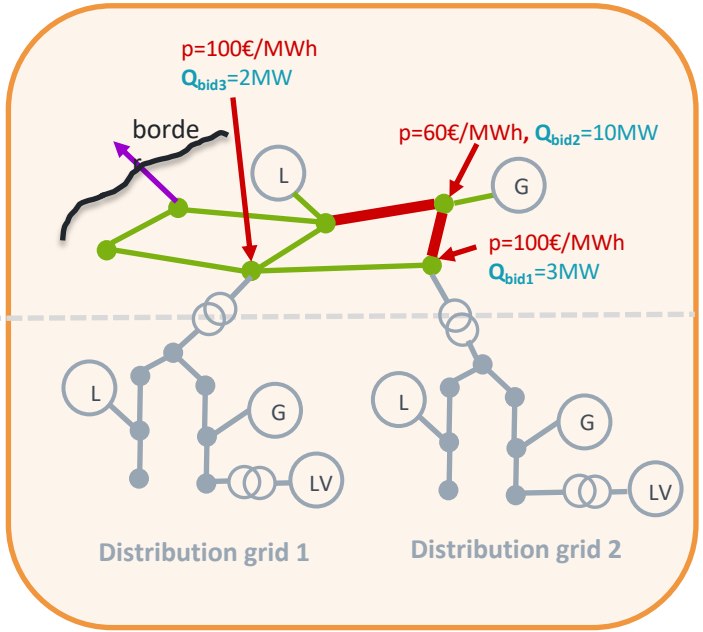
FAT_{max} =Max full activation time for the product



TSO-DSO CS-dependent
Timing Dimension

CS A: Centralized AS market

4 **MO** transmits **market** results to TSO (4) and
5 activates/dispatches FSP (5)



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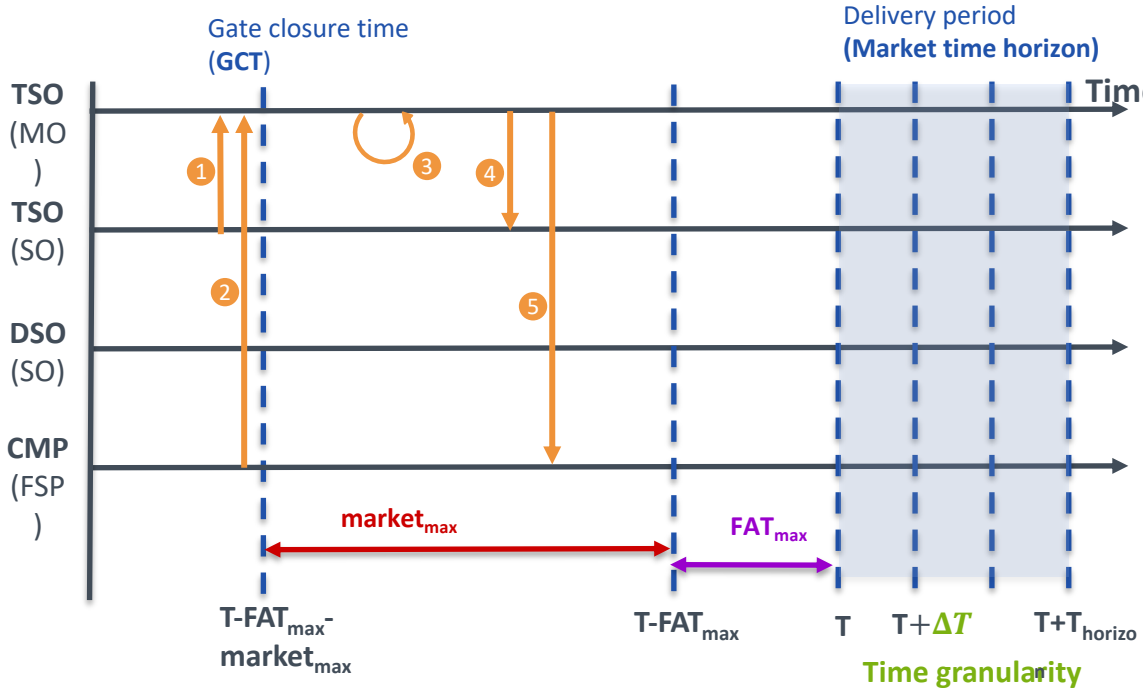
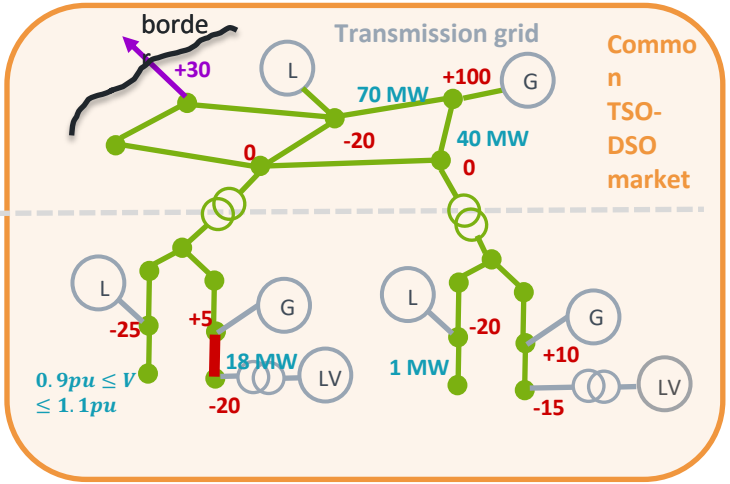


TSO-DSO CS-dependent
Timing Dimension

CS D1: Common TSO-DSO AS market (centralized)

1 **TSO and DSO (SO)** sends their **forecasted grid state**, per market time step (granularity), to the market operator before **GCT**:

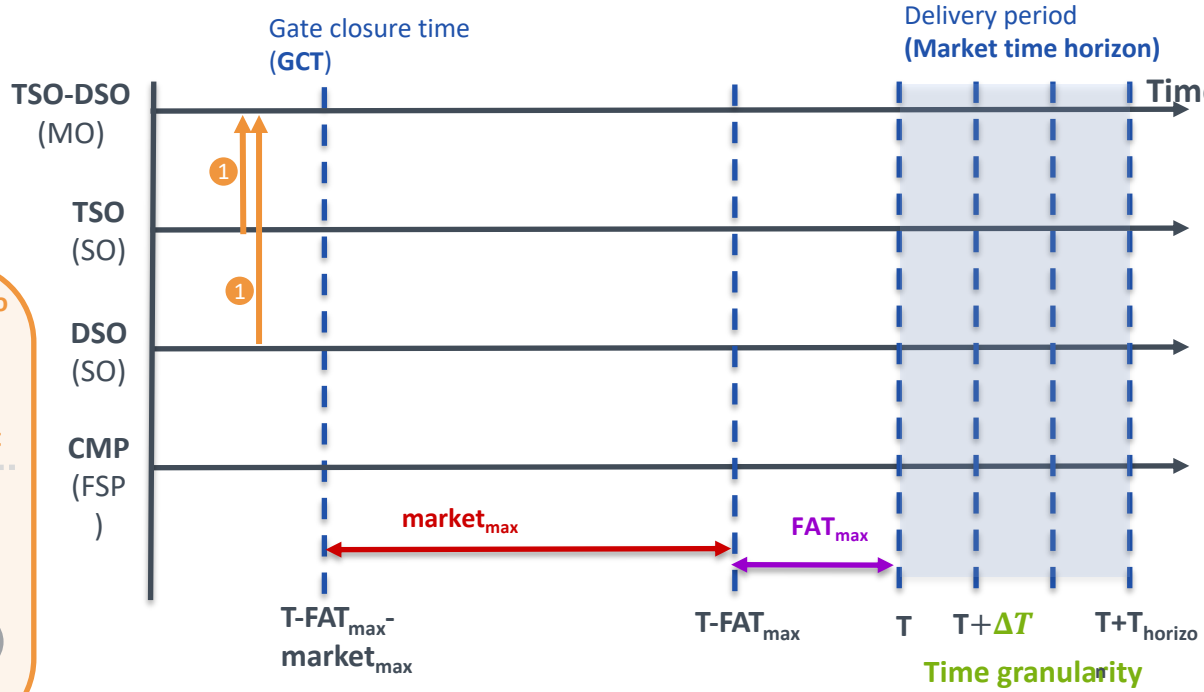
- Forecasted **net nodal power injection**
- **Operational limits** (if changed)
- **Grid topology** (if changed)
- Scheduled/Agreed Flows at **borders**



Forecasted **imbalance = -15MW**

Market$_{max}$ = Max time allowed for market algorithm (+pre/post-processing)

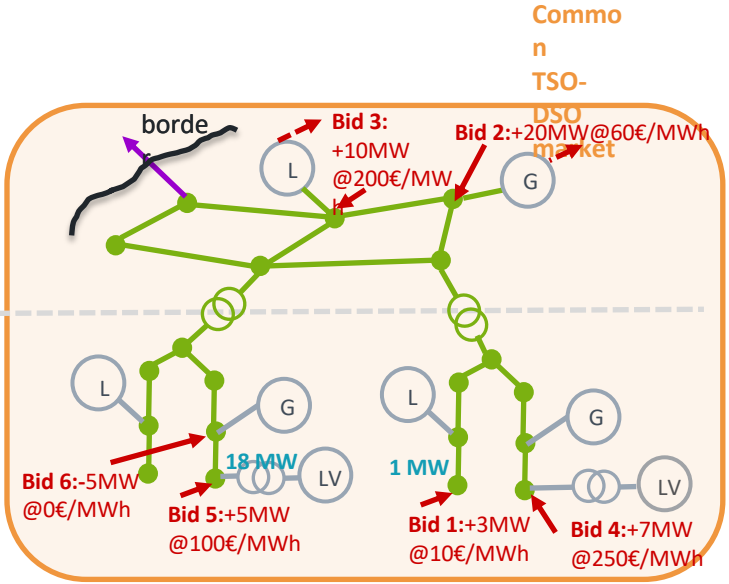
FAT$_{max}$ =Max full activation time for the product



TSO-DSO CS-dependent
Timing Dimension

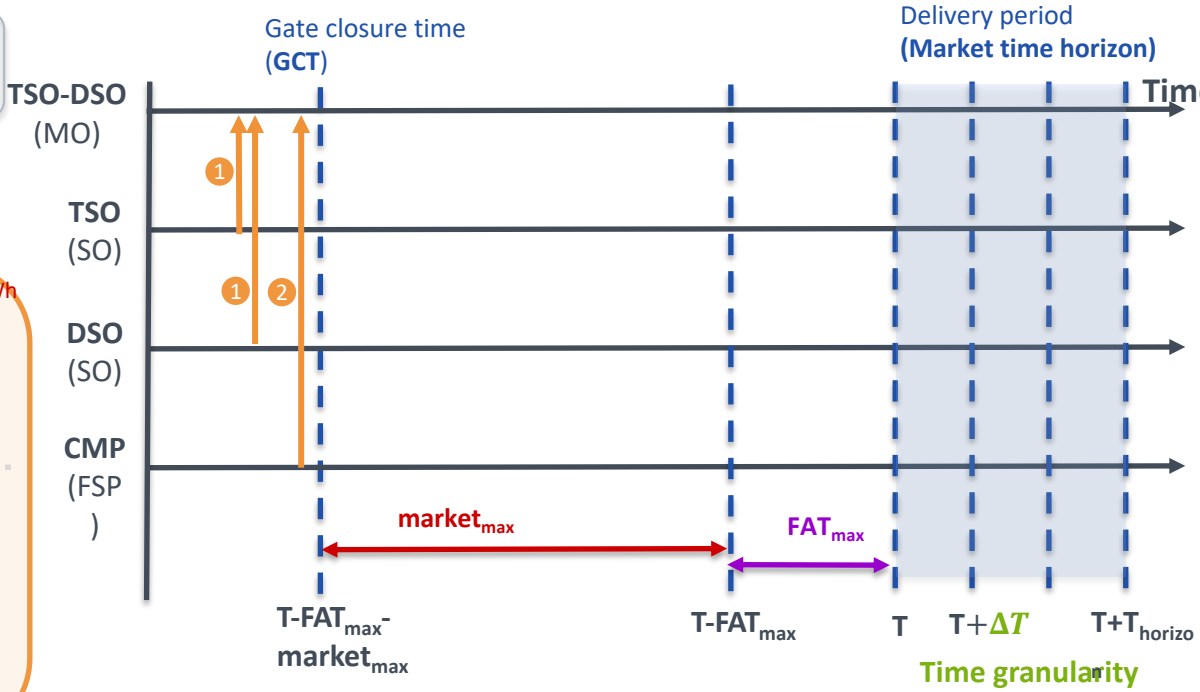
CS D1: Common TSO-DSO AS market (centralized)

2 CMP (FSP: **F**lexibility **S**ervice **P**roviders) send **bids** to the MO (TSO), at **nodal resolution** (MV level for Dx)



Market$_{max}$ = Max time allowed for market algorithm (+pre/post-processing)

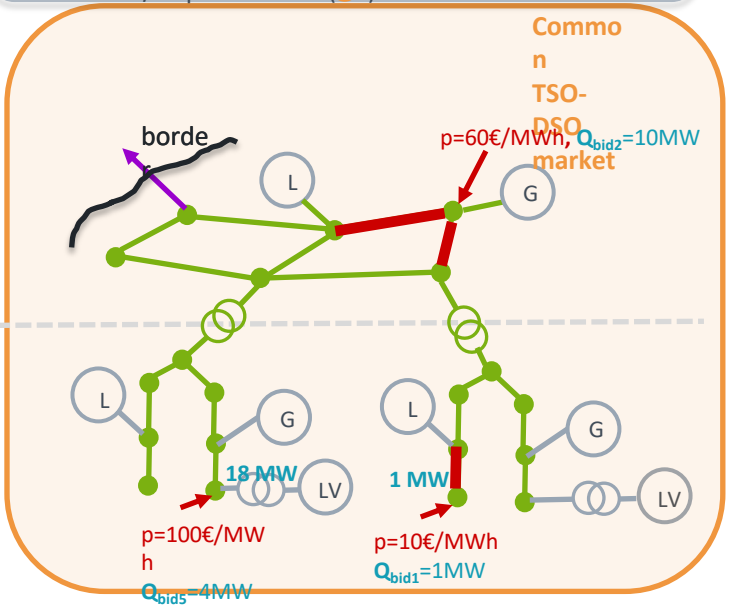
FAT$_{max}$ =Max full activation time for the product



TSO-DSO CS-dependent **Timing** Dimension

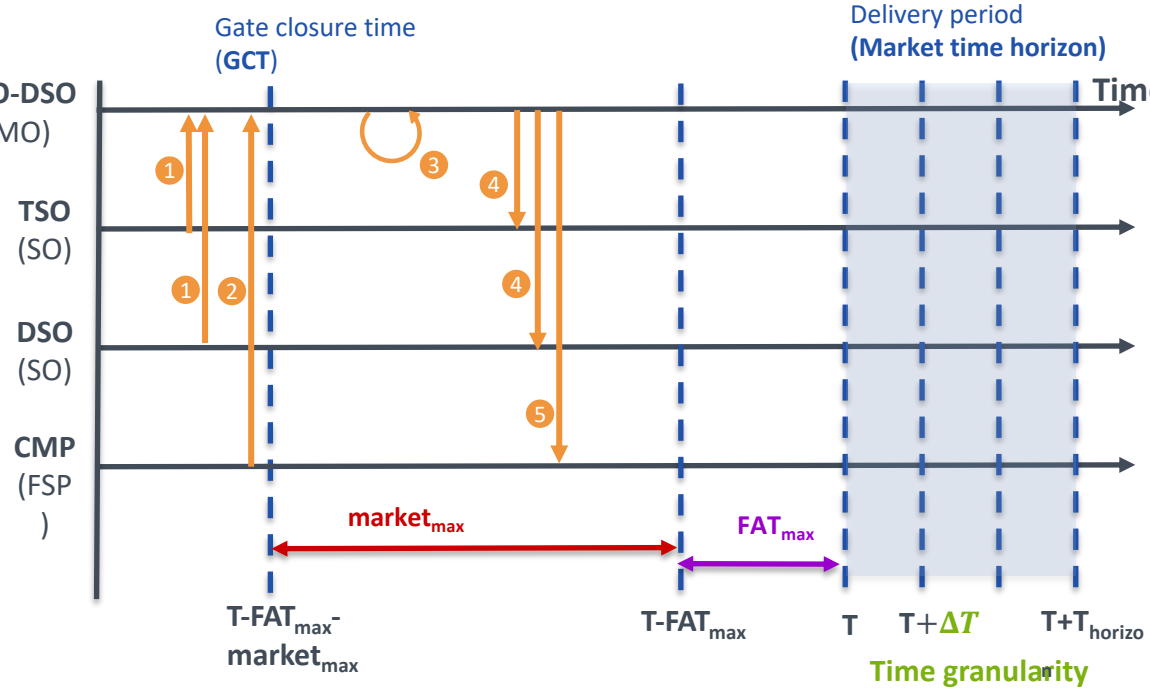
CS D1: Common TSO-DSO AS market (centralized)

3 **MO runs** the **market clearing algorithm**: it computes the accepted bid **quantities** and **nodal** marginal **price**. **MO** transmits **market** results to TSO AND DSO (4) and activates/dispatches FSP (5)



$Market_{max}$ = Max time allowed for market algorithm (+pre/post-processing)

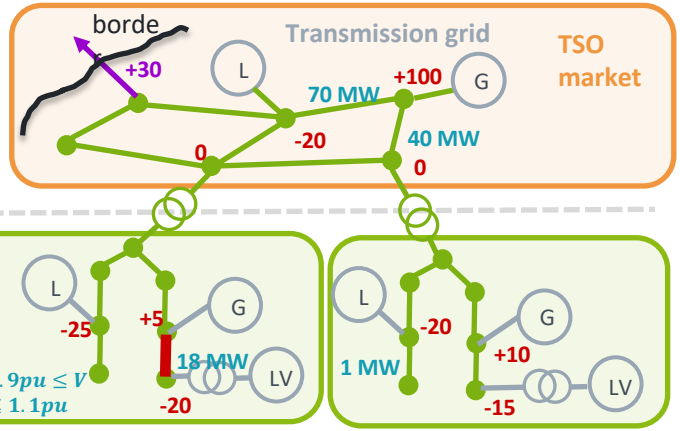
FAT_{max} =Max full activation time for the product



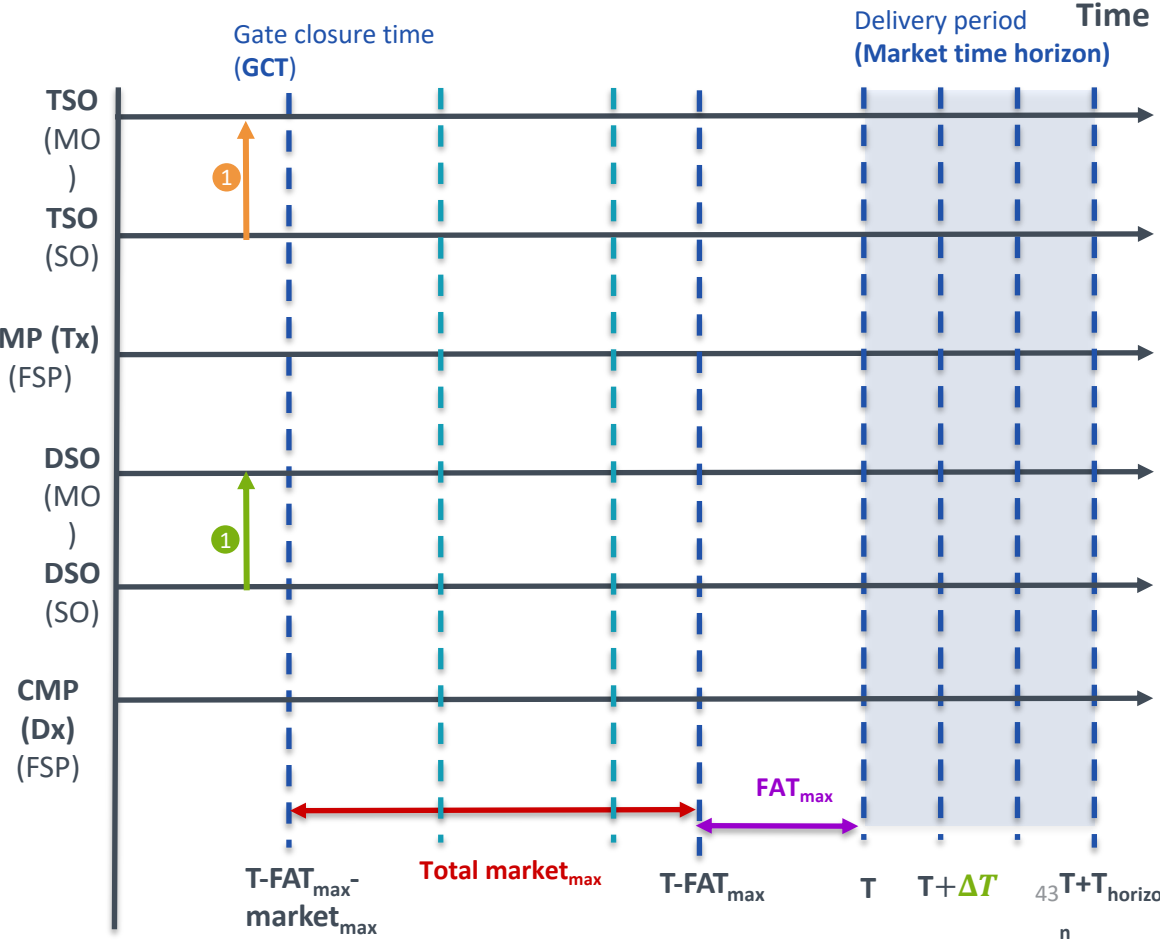
TSO-DSO CS-dependent
Timing Dimension

CS B: Local AS market

1 TSO/DSO (**SO**) send the **forecasted grid state**, per market time step (granularity), to the TSO/DSO (**MO**), before **GCT**:
- Forecasted **net nodal power injection**
- **Operational limits** (if changed)
- **Grid topology** (if changed)
- Scheduled/Agreed Flows at **borders**



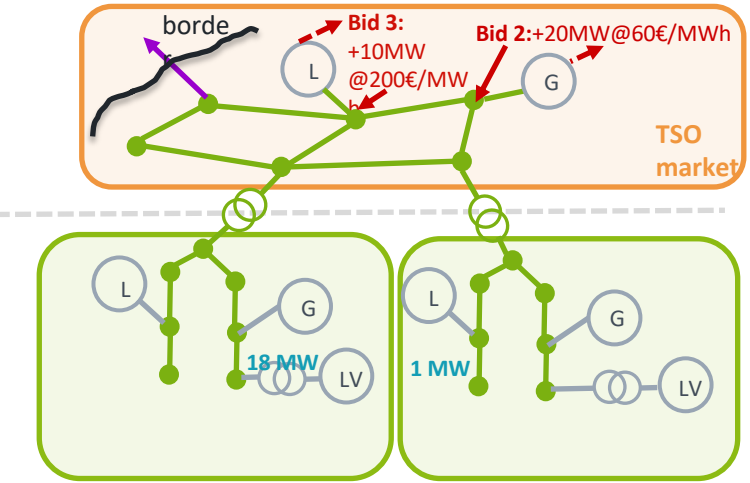
Forecasted **imbalance = -15MW**

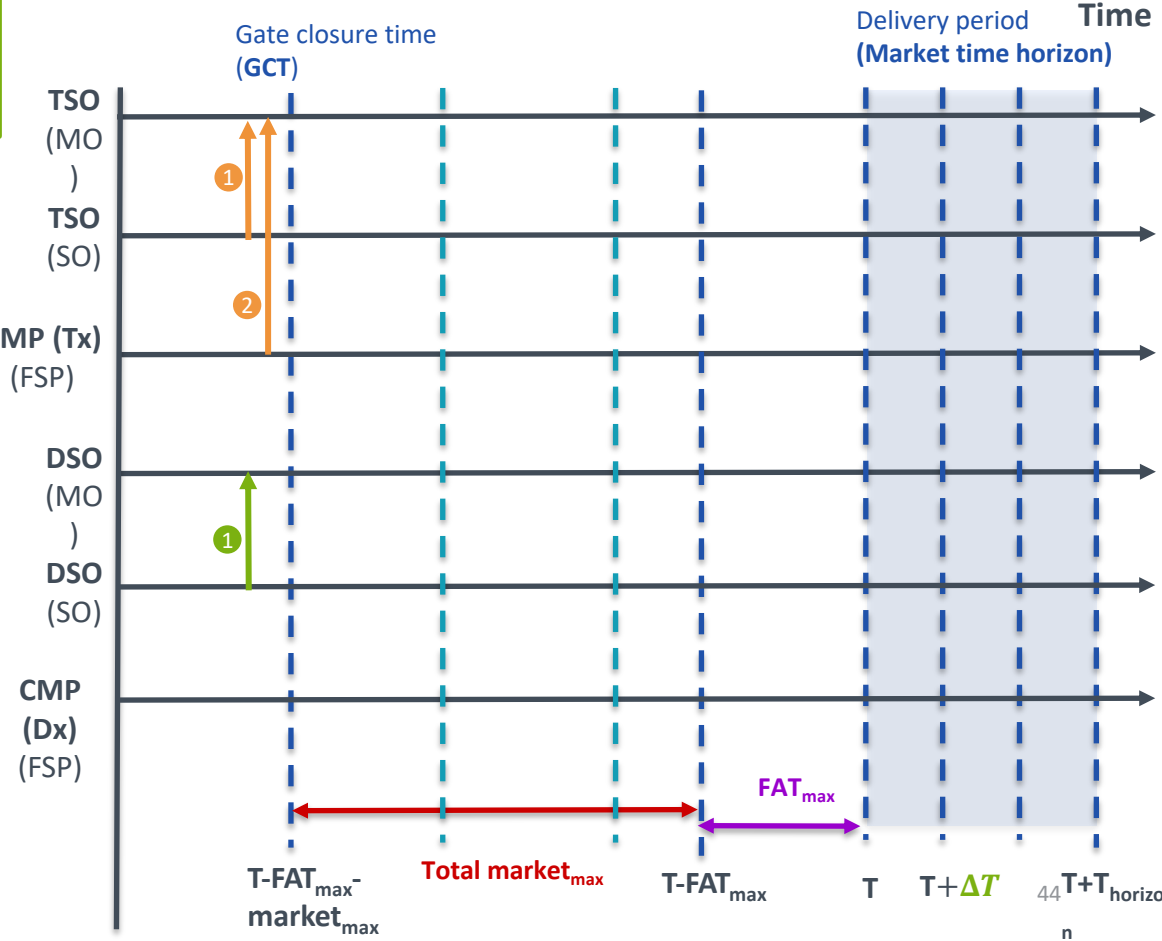


TSO-DSO CS-dependent
Timing Dimension

CS B: Local AS market

2 **CMP** (FSP) send **bids** from **Transmission Grid** connected **resources** to the **MO (TSO),** at **transmission grid nodal resolution**

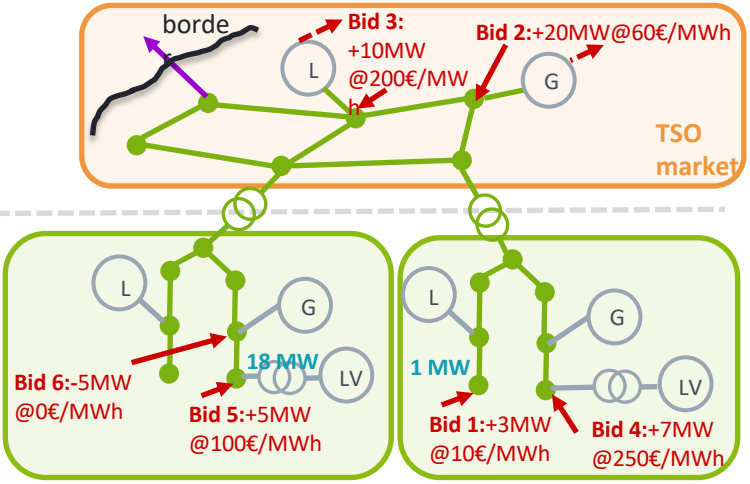


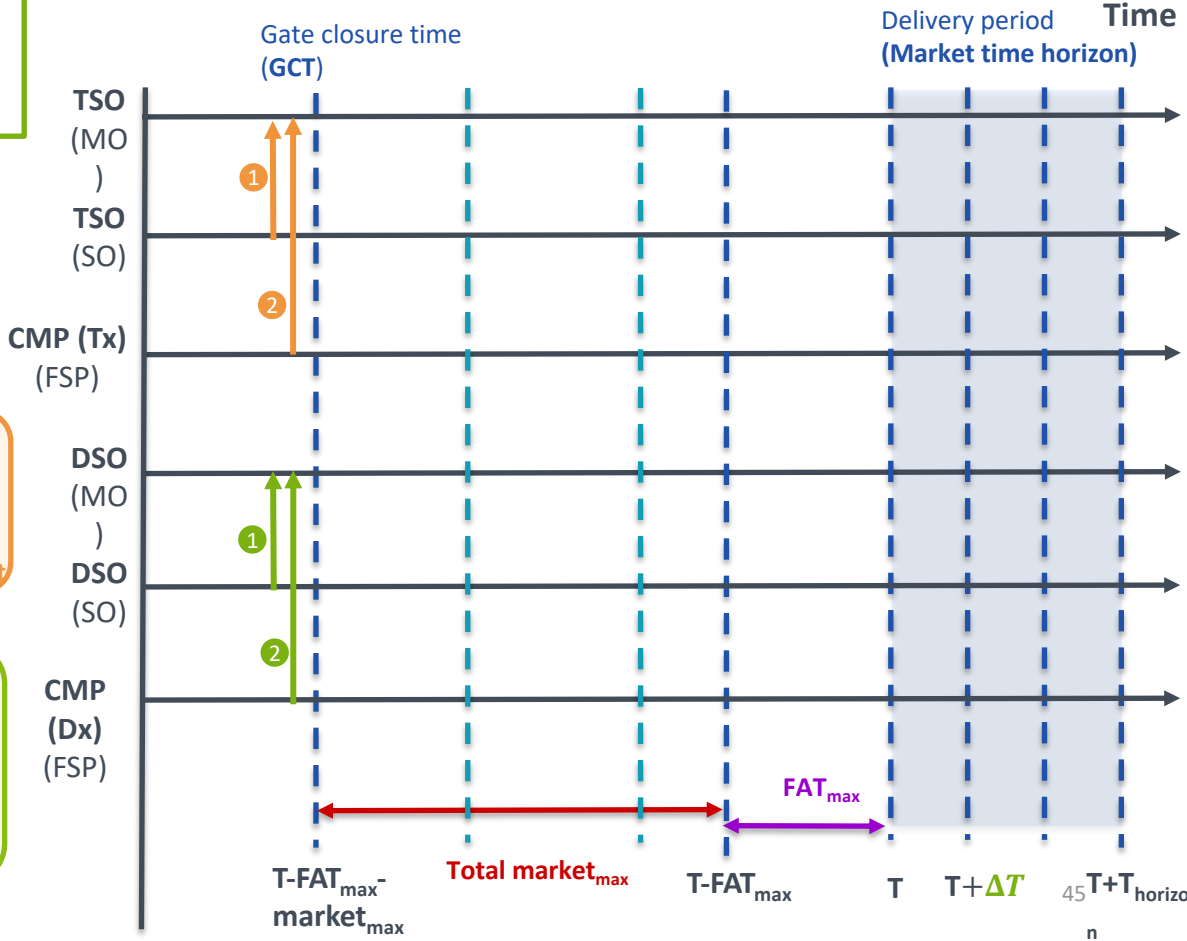


TSO-DSO CS-dependent
Timing Dimension

CS B: Local AS market

2 **CMP** (FSP) send **bids** from **Distribution Grid** connected **resources** to the **MO (DSO),** at **distribution grid nodal resolution (Medium Voltage)**

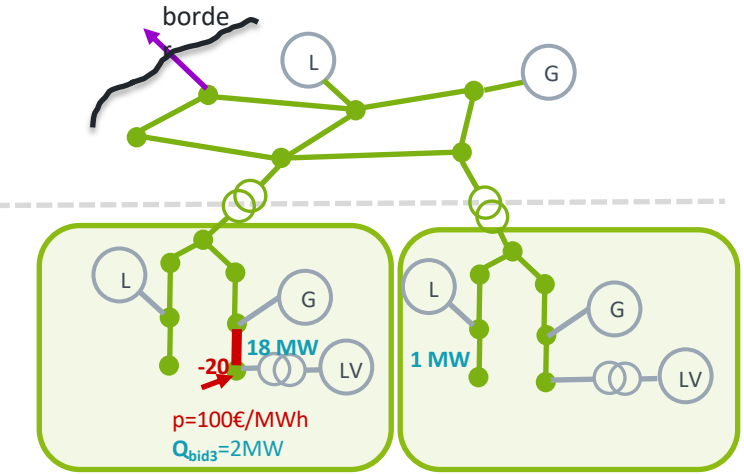


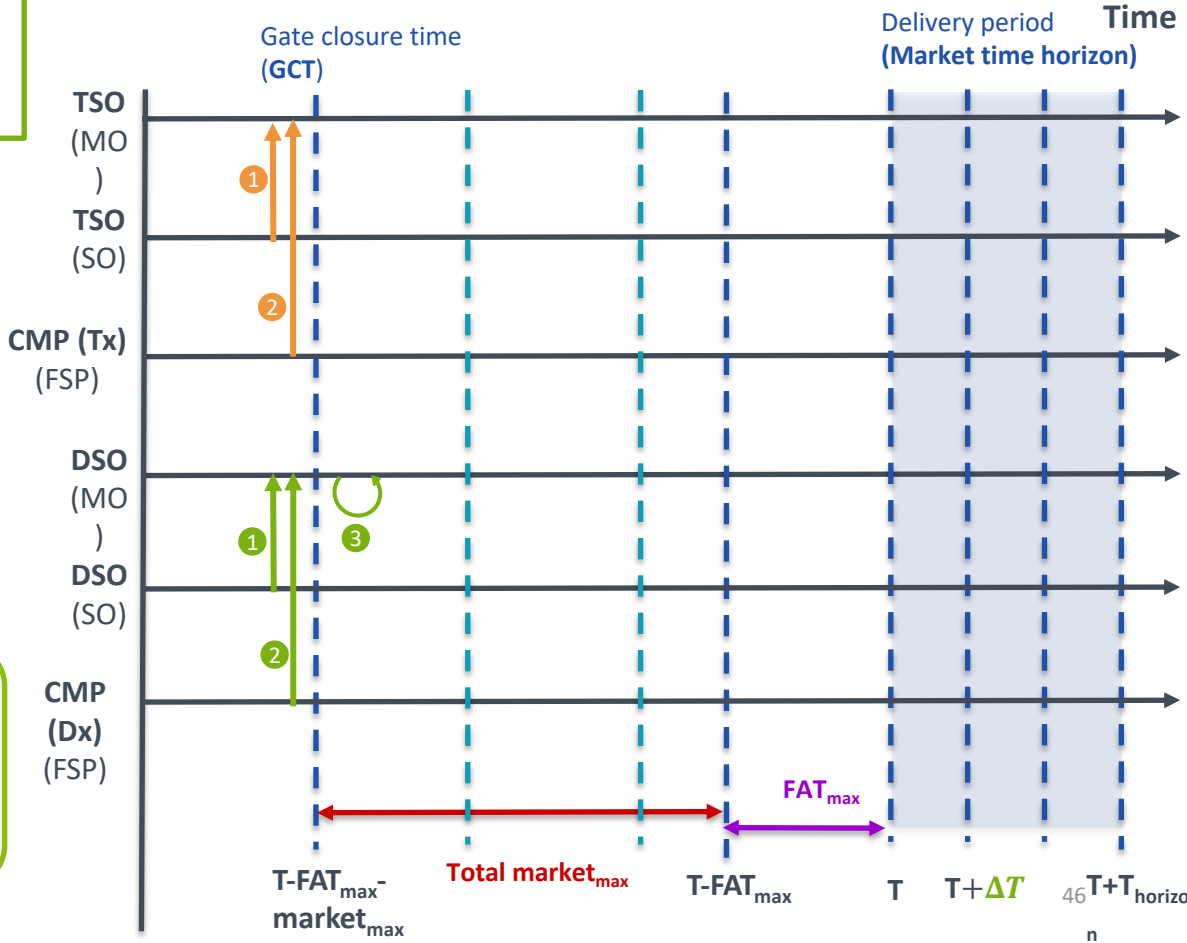


TSO-DSO CS-dependent
Timing Dimension

CS B: Local AS market

3 Each **MO (DSO)** clears its **local market** to **solve** any **local** issues (**congestions**), if any. Bids quantities are then kept aside for the DSO.

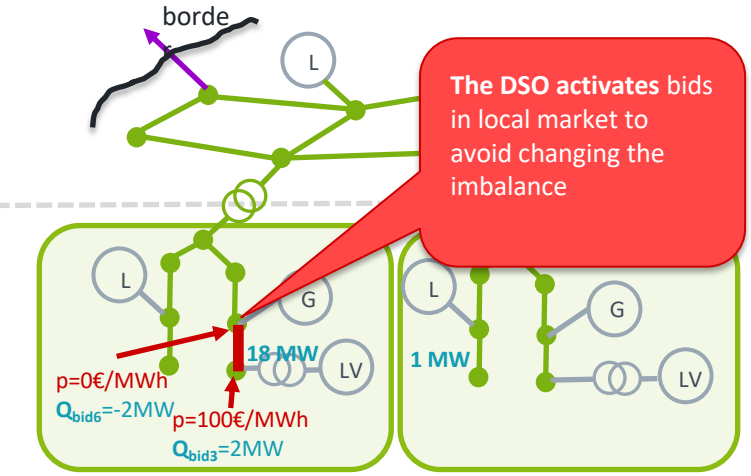


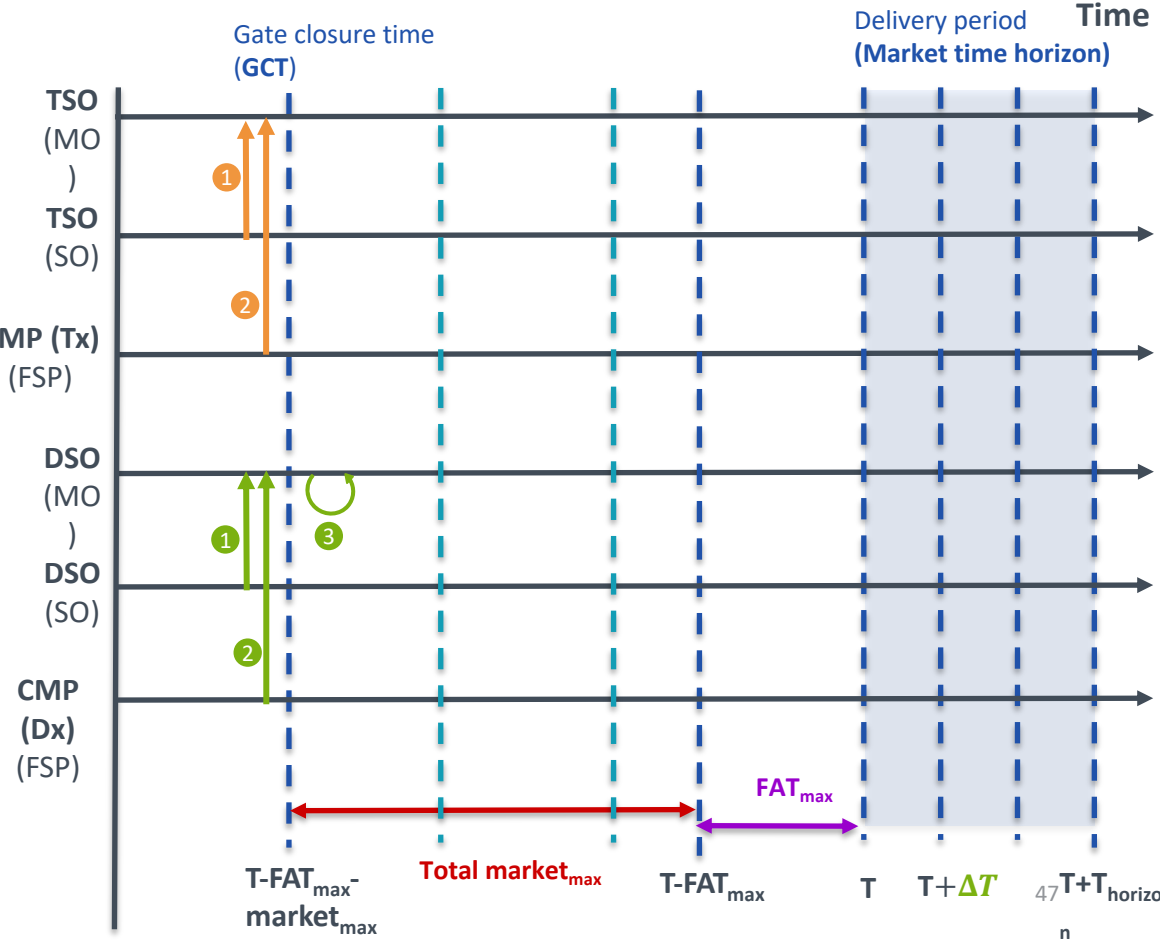


TSO-DSO CS-dependent
Timing Dimension

CS B: Local AS market

3 Each **MO (DSO)** clears its **local market** to **solve** any **local** issues (**congestions**), if any. Bids quantities are then kept aside for the DSO.

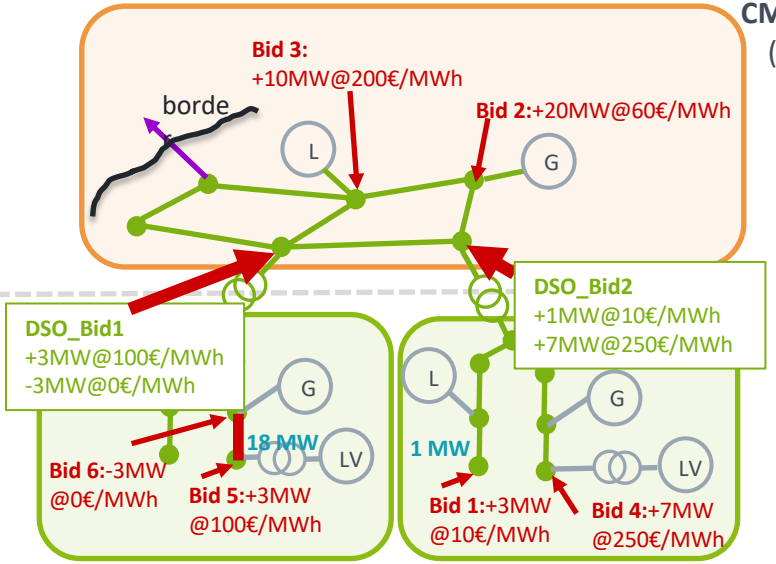


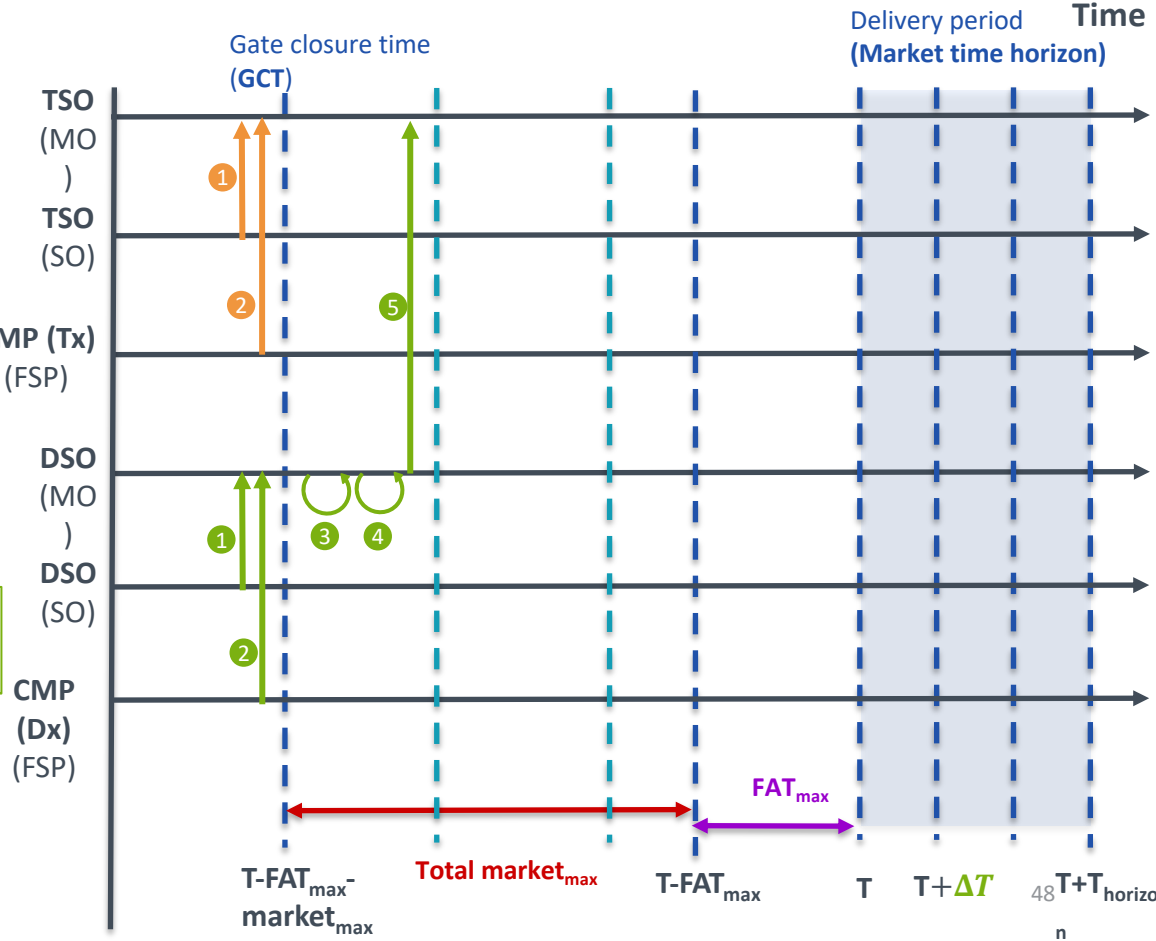


TSO-DSO CS-dependent
Timing Dimension

CS B: Local AS market

4 Each **MO (DSO) aggregates (smartly) remaining** local market bids into a **bid** (or residual supply function) to
5 be submitted to the **TSO (MO) market,** before **GCT_{TSO}**

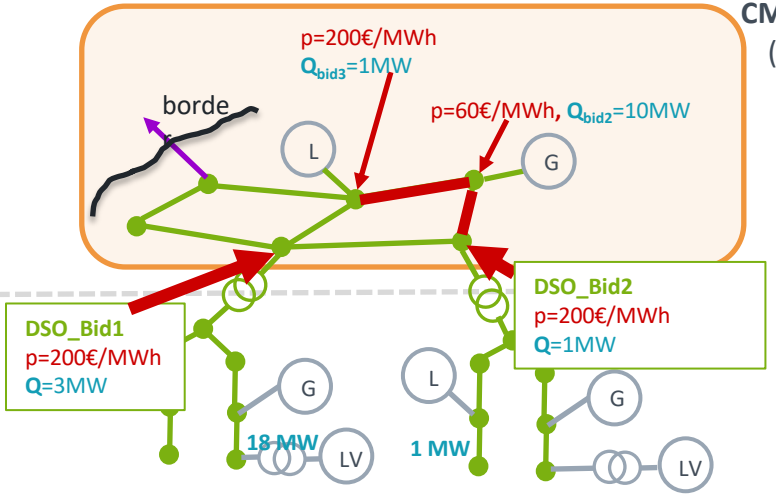


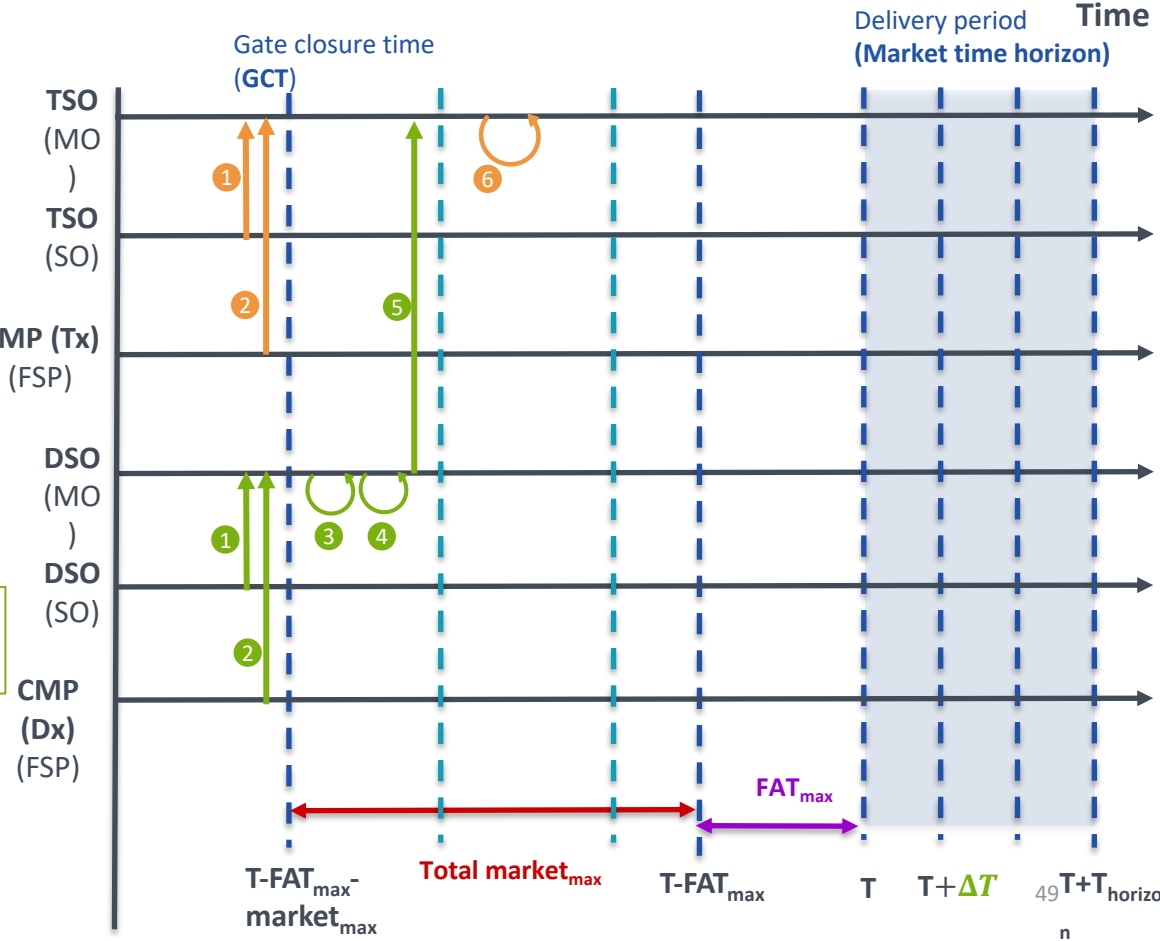


TSO-DSO CS-dependent
Timing Dimension

CS B: Local AS market

6 MO (TSO) **runs** the **market clearing algorithm**: it computes the accepted bid **quantities** and **nodal** marginal **price**.

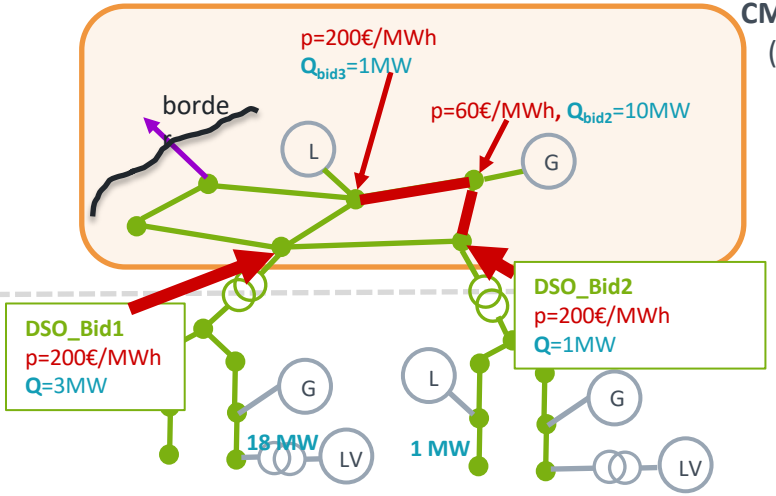


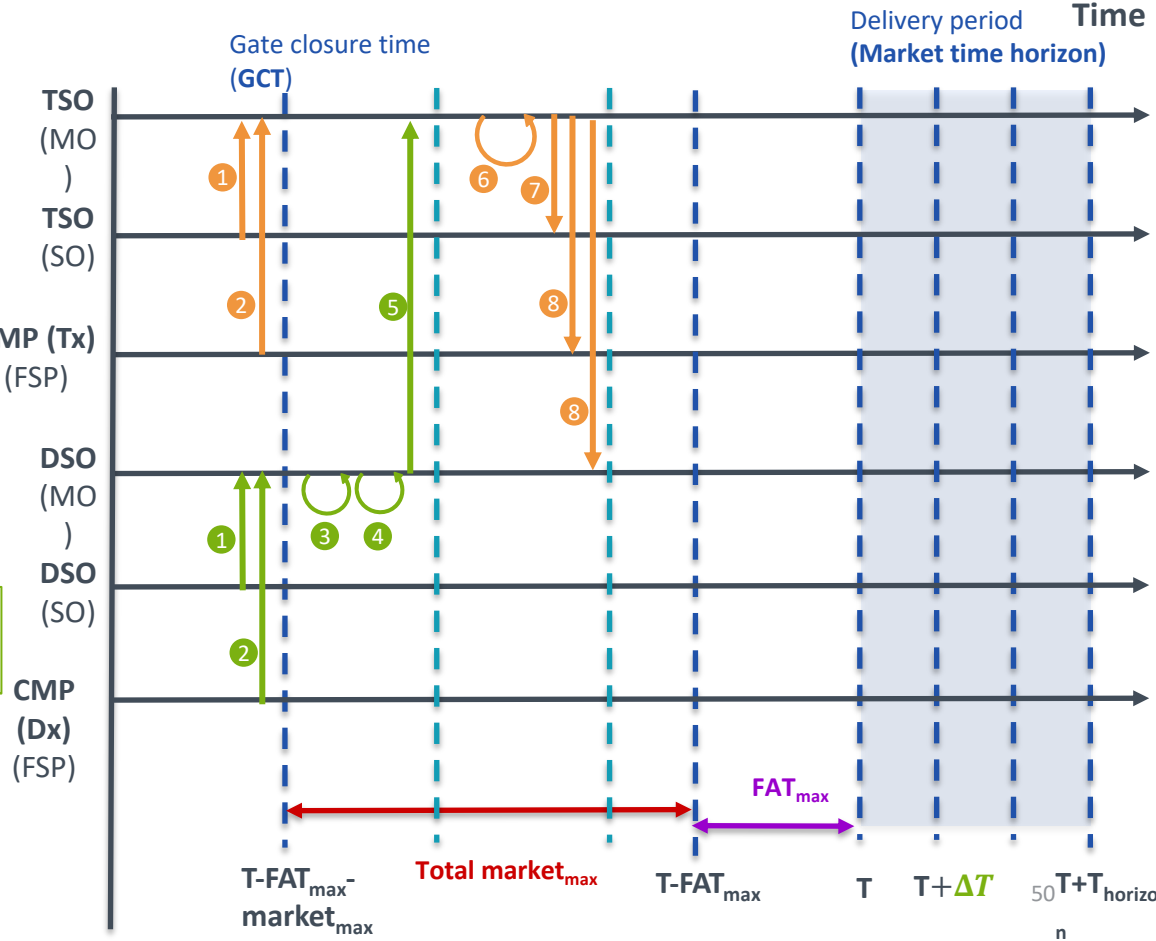


TSO-DSO CS-dependent
Timing Dimension

CS B: Local AS market

7 8 **MO (TSO)** transmits **market** results to TSO (7) and activates/dispatches FSP (8), both **CMP (Tx)** and **DSOs (MO)**

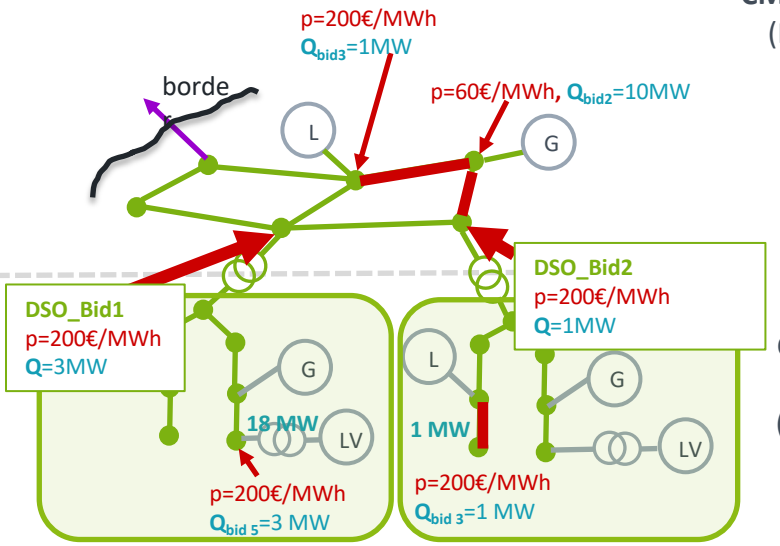


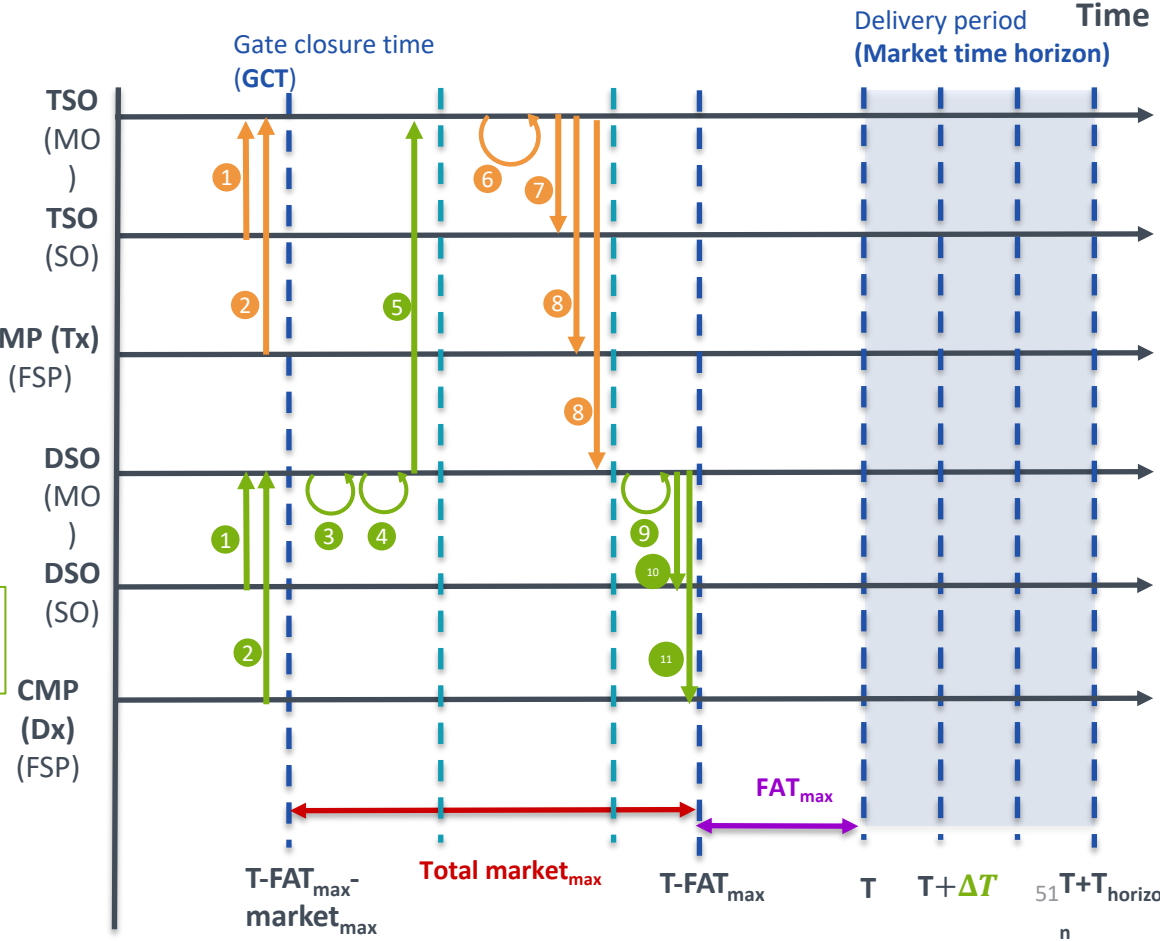


TSO-DSO CS-dependent
Timing Dimension

CS B: Local AS market

MO (DSO) perfoms the disaggregation (9), transmits market results to **DSO (SO)** (10) and activates/dispatches FSP (11)



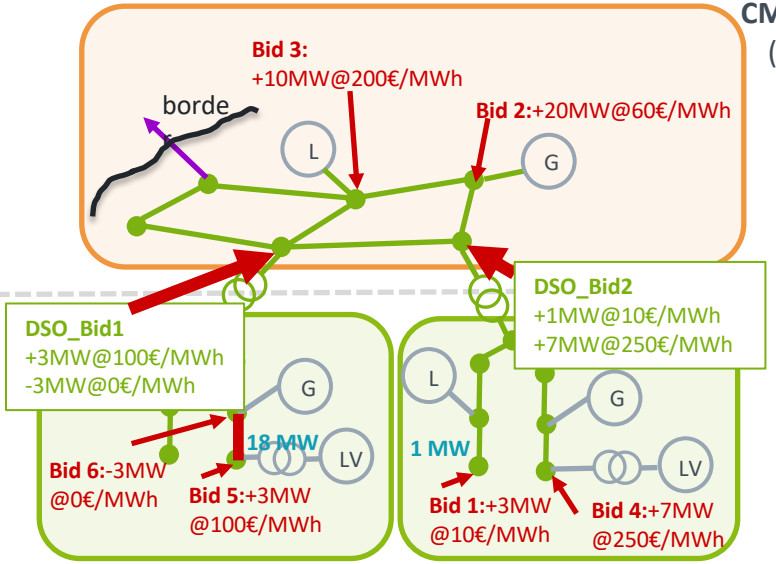


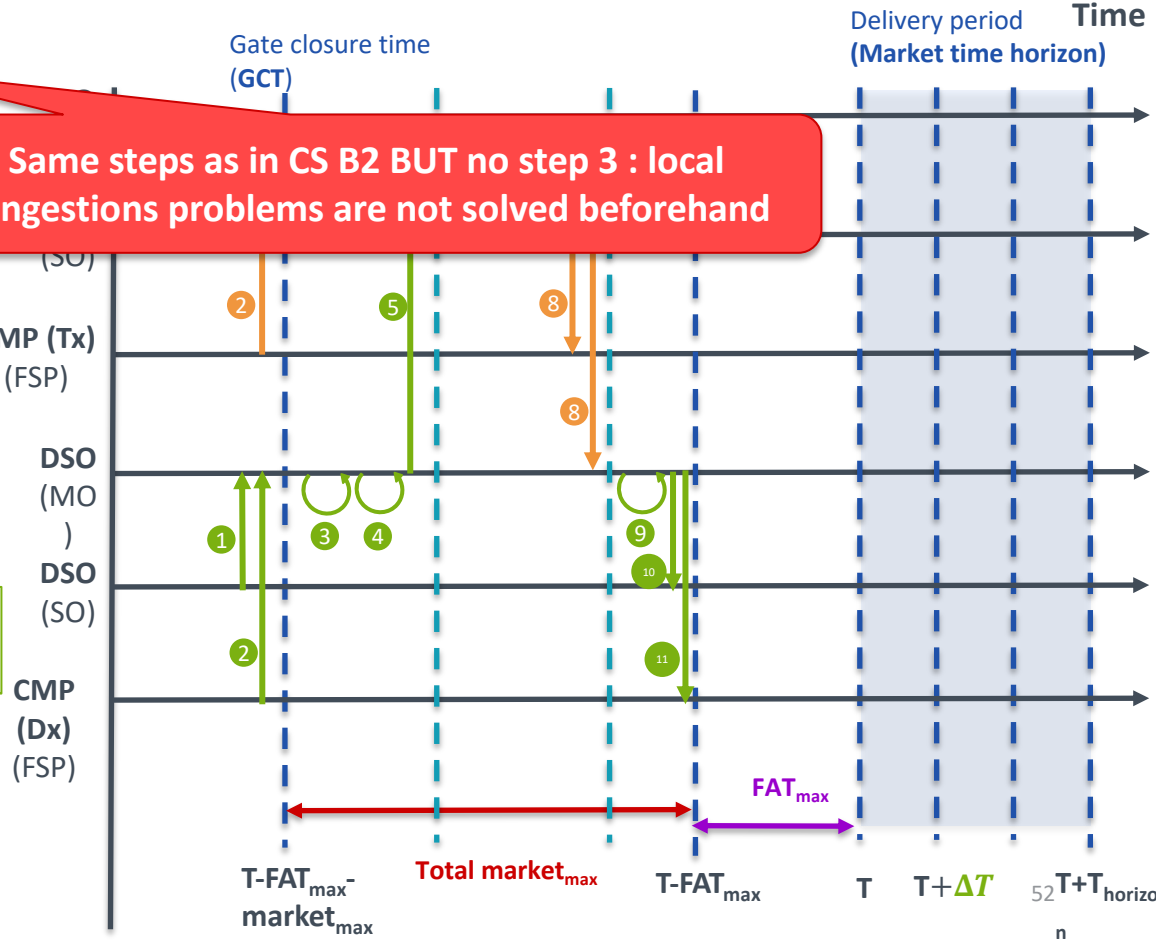
TSO-DSO CS-dependent
Timing Dimension

CS D2: Common TSO-DSO AS market (decentralized)

Same steps as in CS B2 BUT no step 3 : local congestions problems are not solved beforehand

4 Each **MO (DSO) aggregates (smartly) remaining** local market bids into a **bid** (or residual supply function) to
5 be submitted to the **TSO (MO) market,** before **GCT_{TSO}**

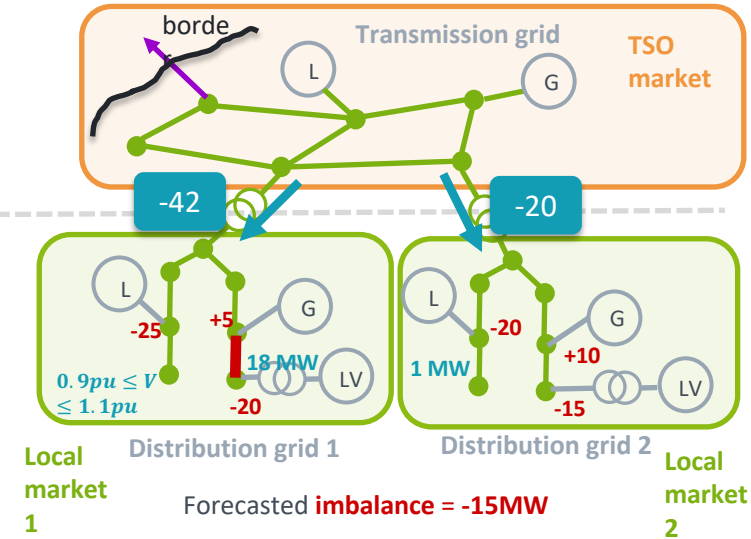


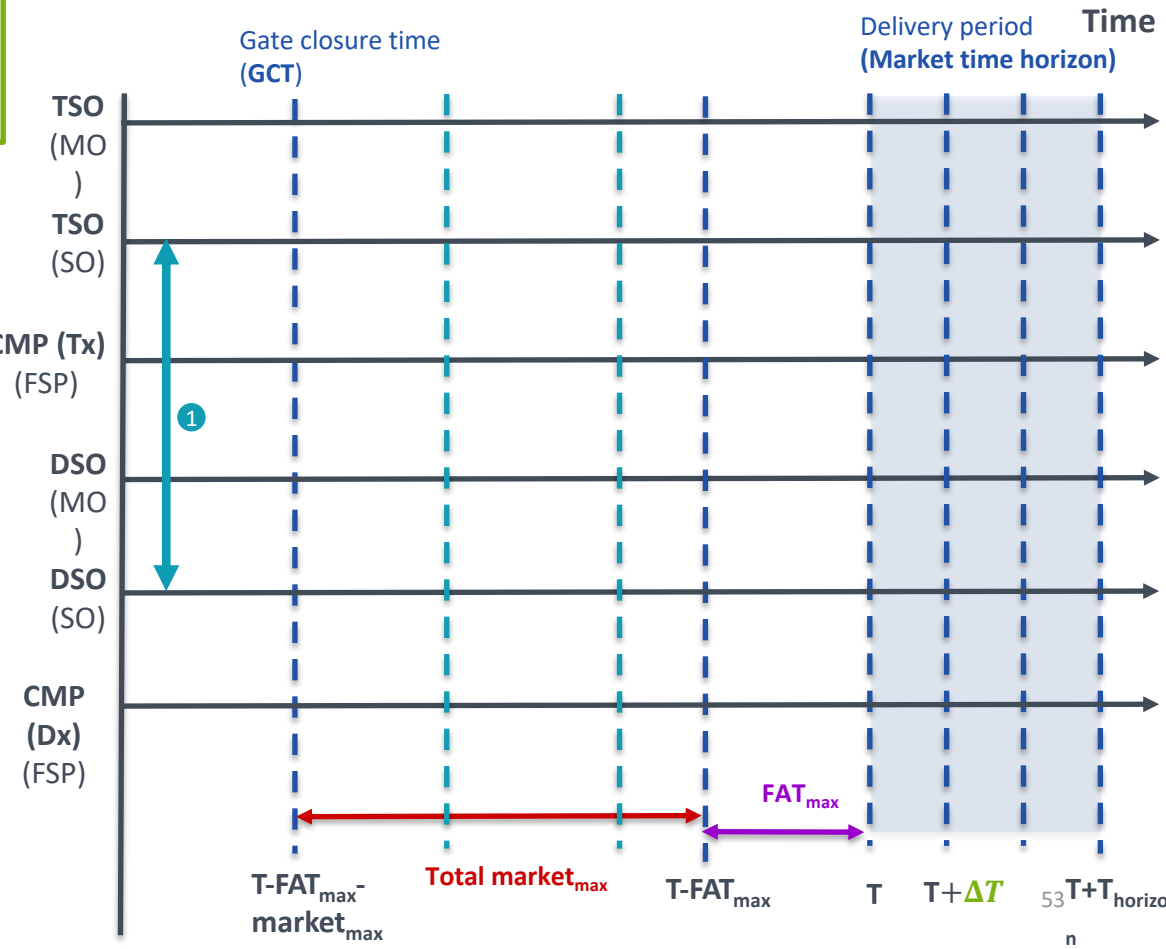


TSO-DSO CS-dependent
Timing Dimension

CS C: Shared balancing responsibility

1 TSO/DSO (**SO**) agree and define a **schedule** for the exchange of power at each primary substation (HV-MC connecting edge)



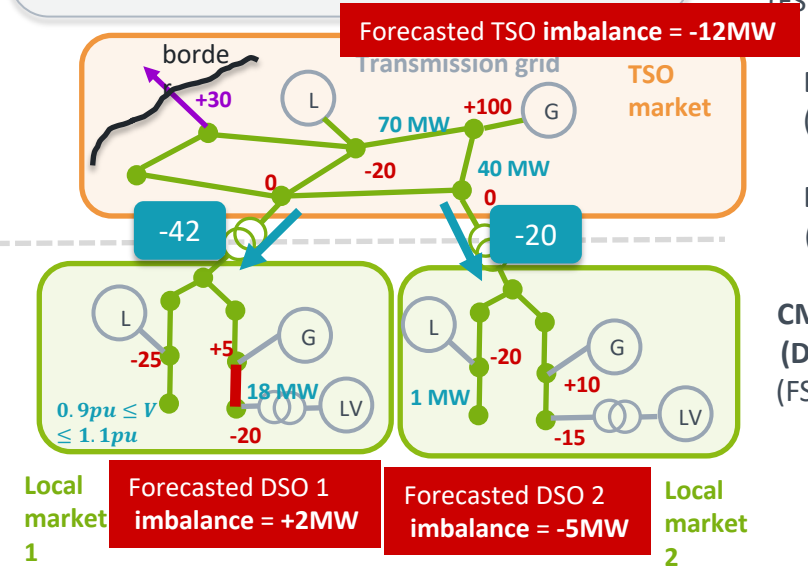


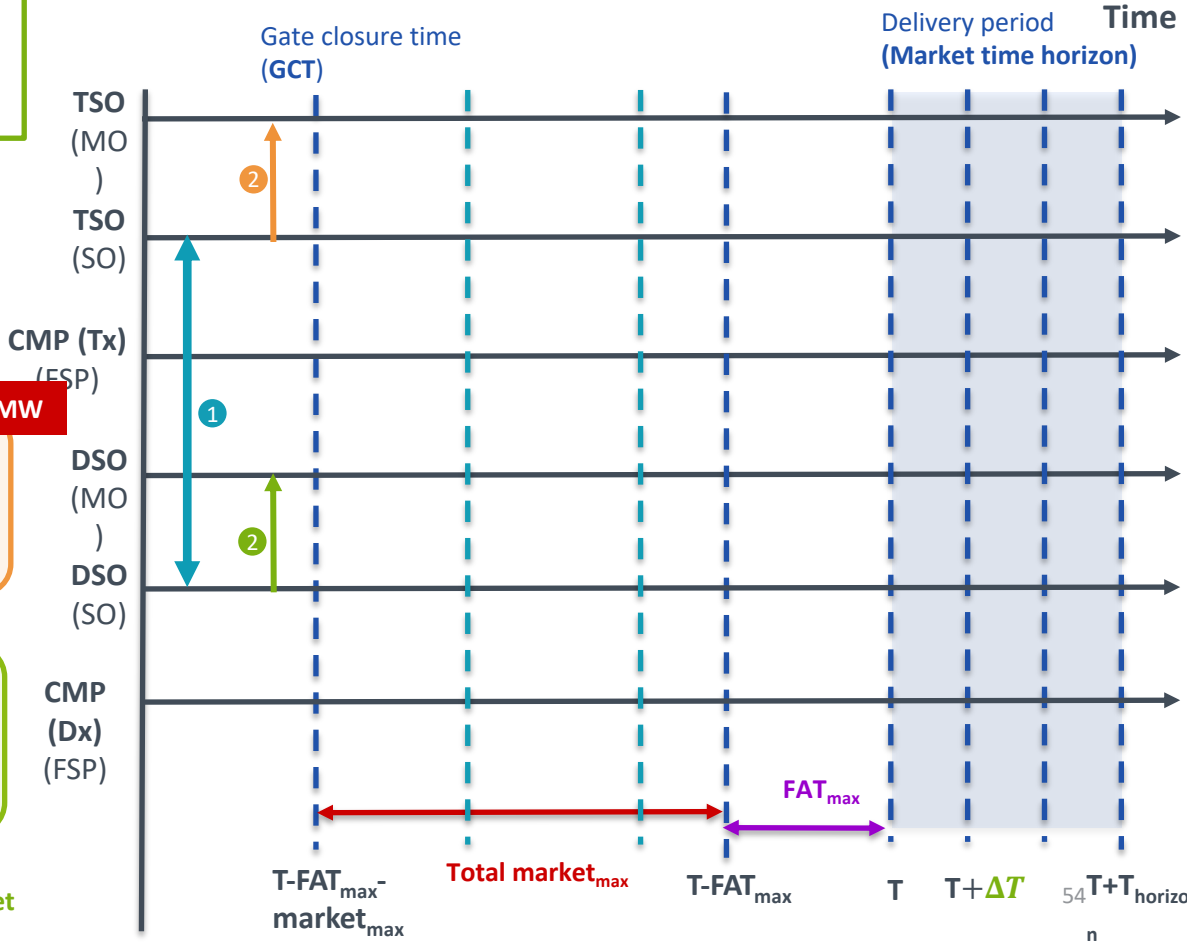
TSO-DSO CS-dependent
Timing Dimension

CS C: Shared balancing responsibility

2 TSO/DSO (**SO**) send the **forecasted grid state**, per market time step (granularity), to the TSO/DSO (**MO**), before **GCT**:

- Forecasted **net nodal power injection**
- **Operational limits** (if changed)
- **Grid topology** (if changed)
- Scheduled/Agreed Flows at **borders**

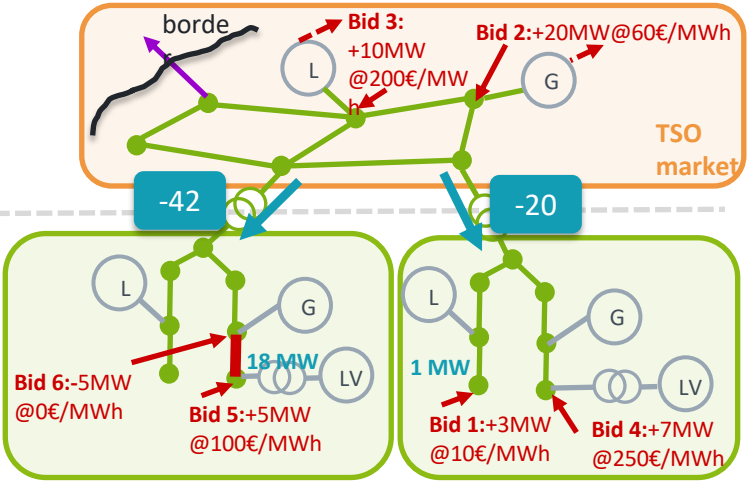


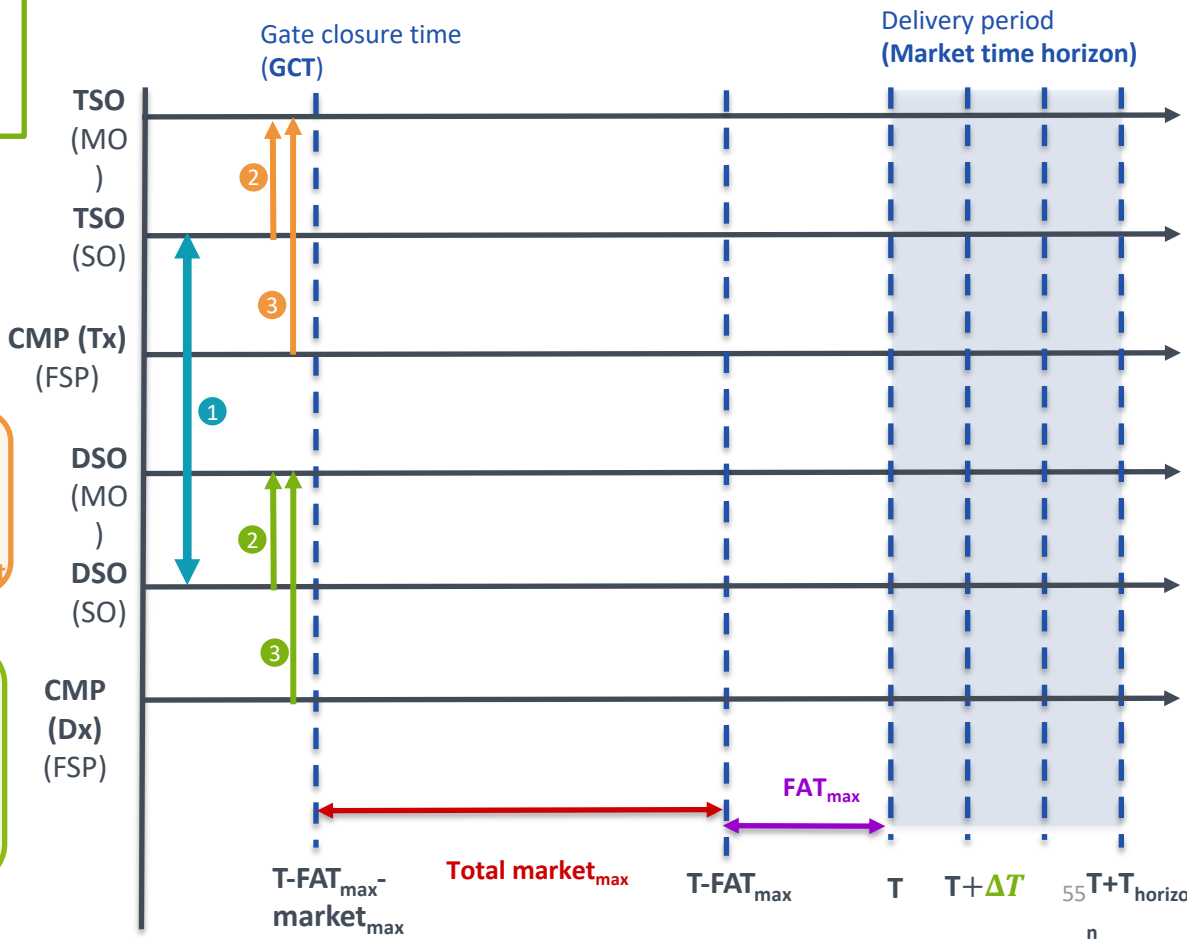


TSO-DSO CS-dependent
Timing Dimension

CS C: Shared balancing responsibility

3 **CMP**(Dx)/**CMP**(Tx) send **bids** from
3 **Distribution**/**Transmission Grid** connected **resources** to the **MO (DSO)**/ **MO (TSO)**, at **distribution/transmission grid nodal resolution**

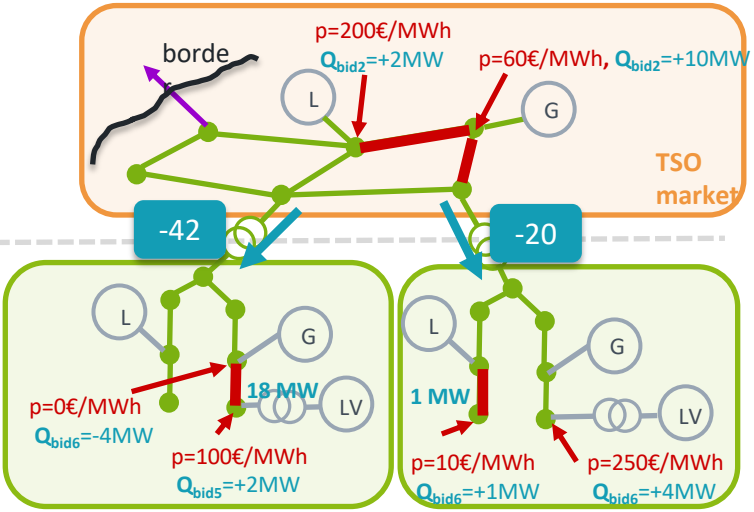


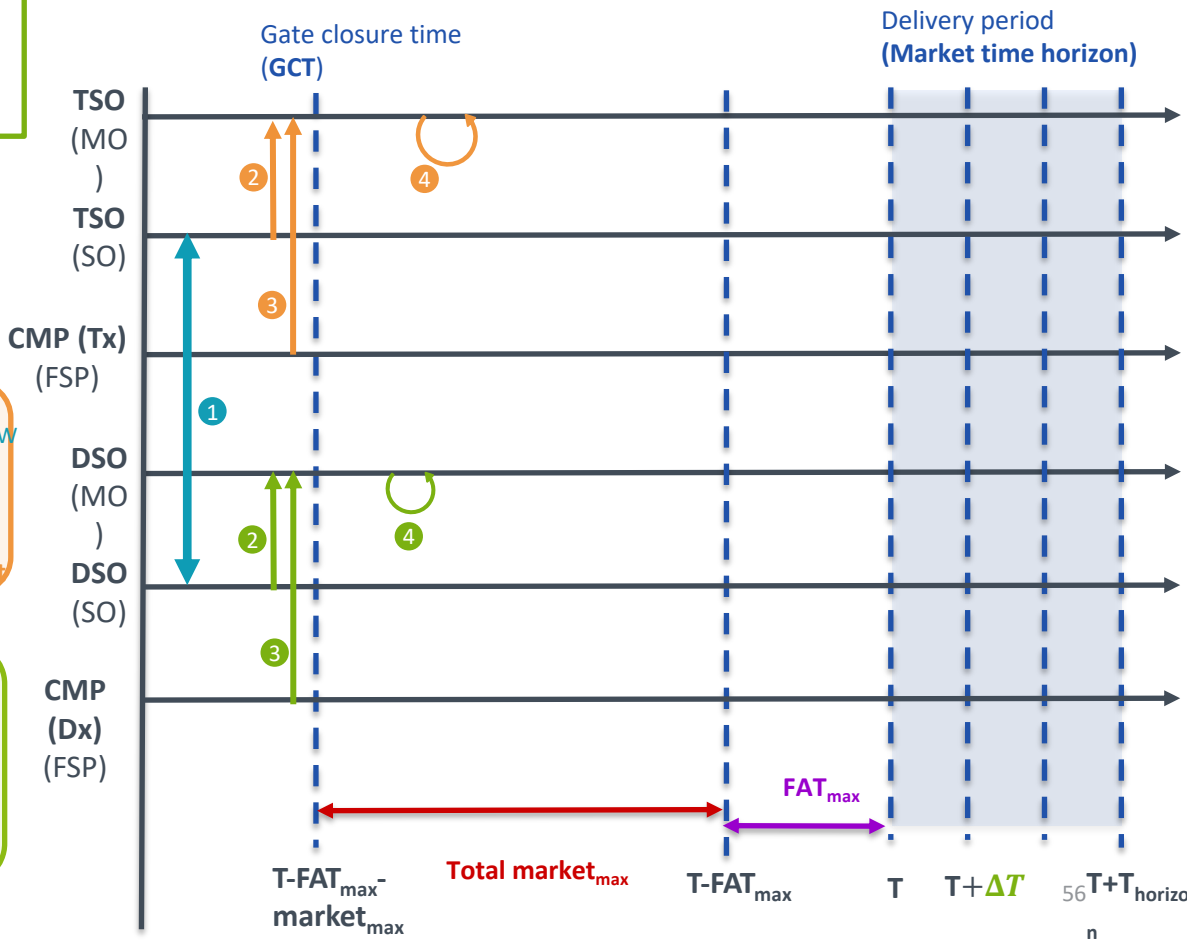


TSO-DSO CS-dependent
Timing Dimension

CS C: Shared balancing responsibility

4 MO (**TSO**)/MO(**DSO**) **runs** the **market clearing**
4 **algorithm**: it computes the accepted bid **quantities** and **nodal** marginal **price**.





TSO-DSO CS-dependent
Timing Dimension

CS C: Shared balancing responsibility

MO (TSO)/MO(DSO) transmits **market** results to TSO (5 5) and activates/dispatches CMP (6 6