N-SIDE
OPTIMIZING YOUR DECISIONS

SmartNet

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

Public Workshop
20 June 2018

Real-time market architectures

Market design for provision of **ancillary services** from DER for different **TSO-DSO** coordination schemes

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Outline

- SmartNet AS **market scope** in the simulation platform
- **Market design ingredients**
  - Key **generic** ingredients
  - **TSO-DSO** coordination scheme **specifics**
- **Challenges**

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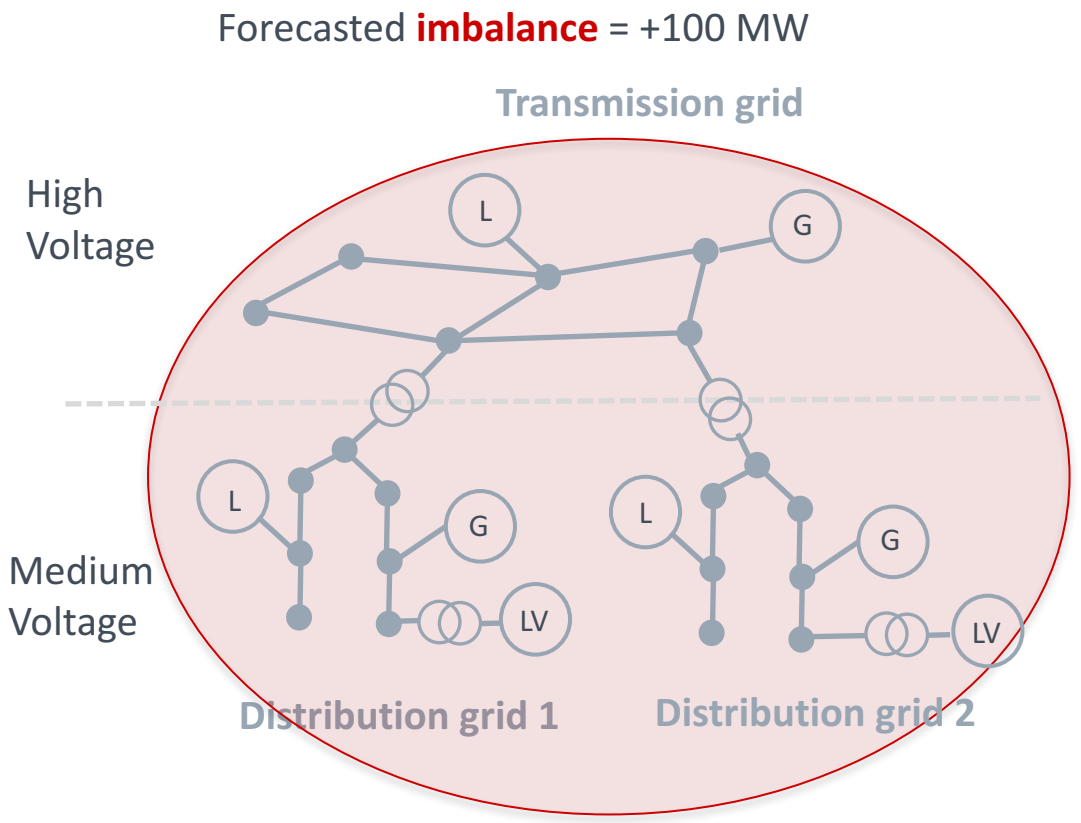
- **Challenges**

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

- **Balancing** services



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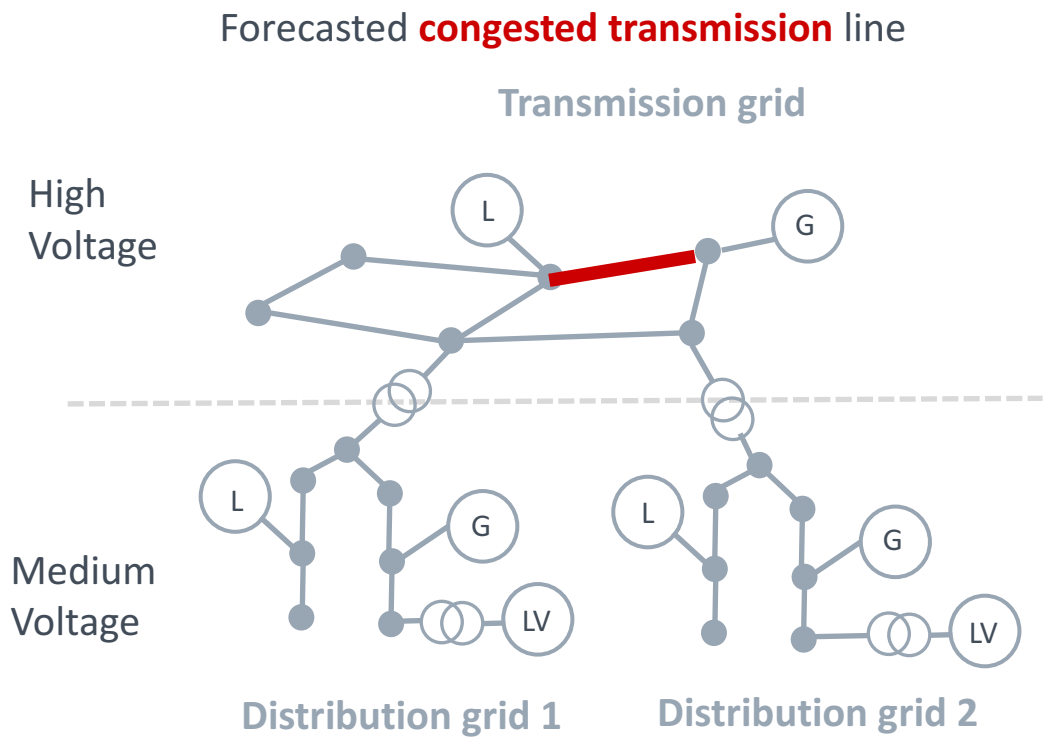
- **Balancing** services
- **Congestion** management
  - At the **transmission** grid level



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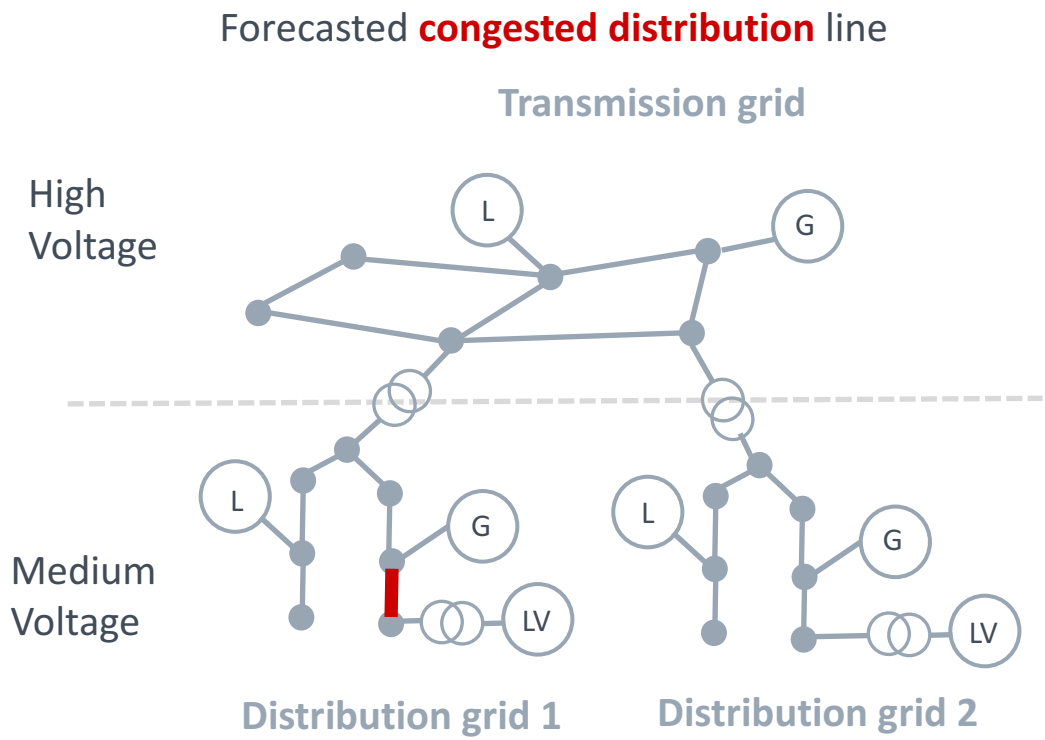
  - At the **transmission** grid level
  - At the **distribution** grid level (medium voltage)



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

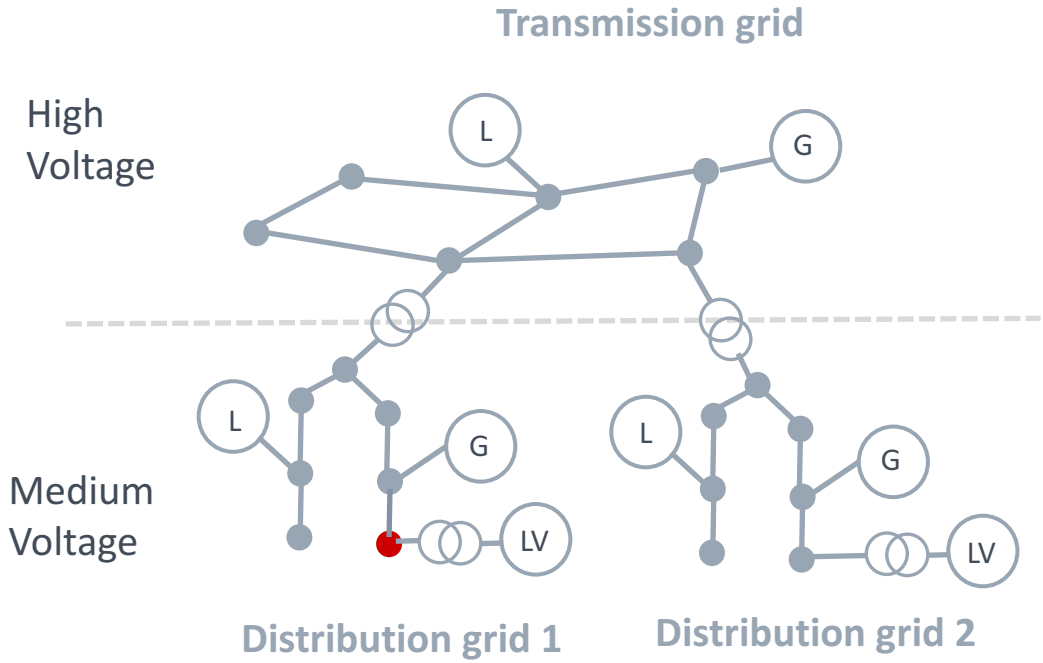
- **Balancing** services
- **Congestion** management
  - At the **transmission** grid level
  - At the **distribution** grid level (medium voltage)

- 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**

➔ 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:
    - aFRR: update of set points every few seconds
    - FCR: local controller reacting on local frequency measurements

LV

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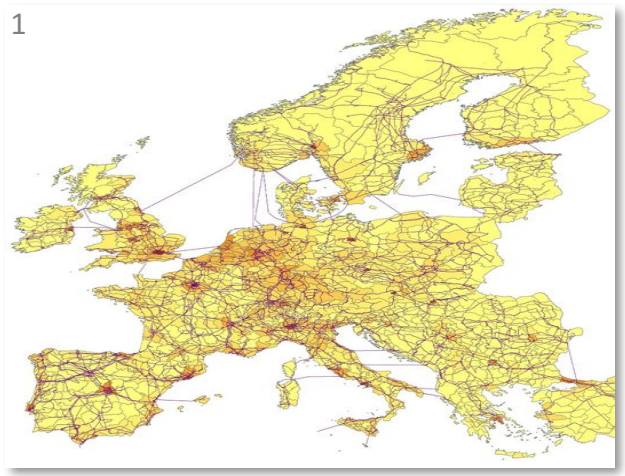
Key **market design ingredients**

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**, time **granularity** and **horizon** ?
Bidding Dimension	How market actors can bid ? What market products are proposed?
Clearing Dimension	What are the objectives of the market clearing ?
Pricing Dimension	What price is paid to the activated bids ?

Network
Dimension

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

Transmission grid



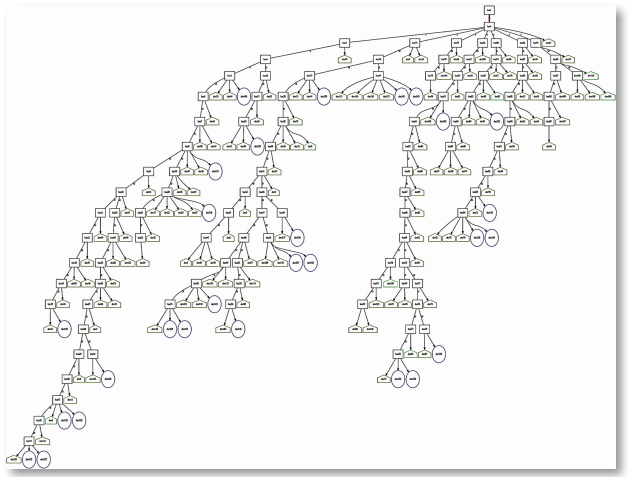
+ Accuracy

+ Numerical Complexity

Copper plate — LP — AC (NLP)

+

MV **distribution** grid



+ Accuracy

+ Numerical Complexity

Copper 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*)

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

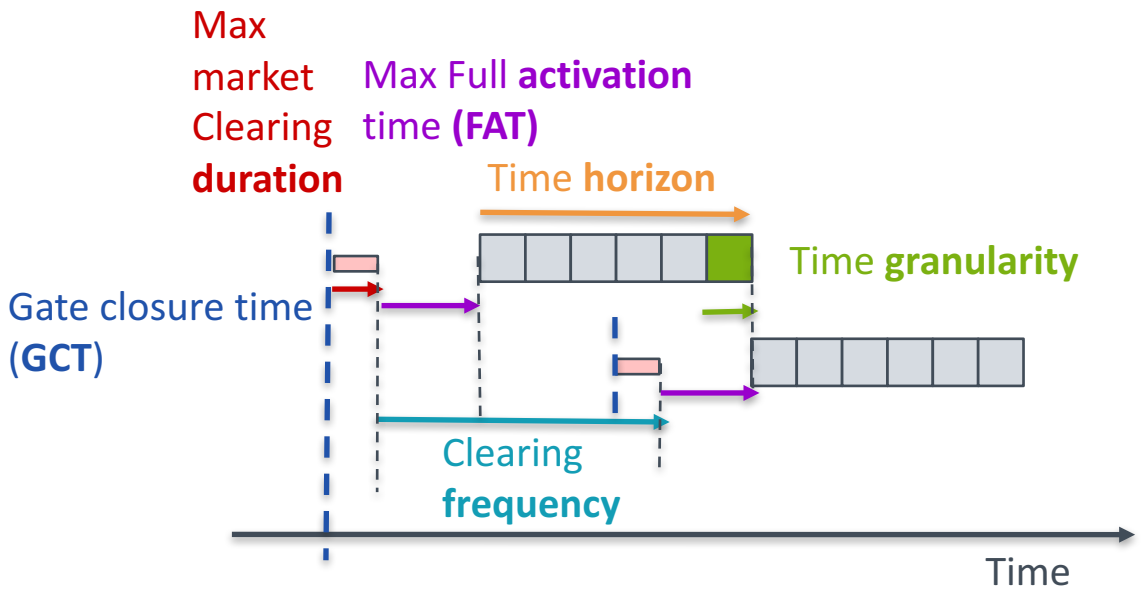
2) **Linear Ben-Tal relaxation** model
   - **Linearize** conic constraints
   - Allows to use efficient MILP warm-start capabilities of (commercial) solvers

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)

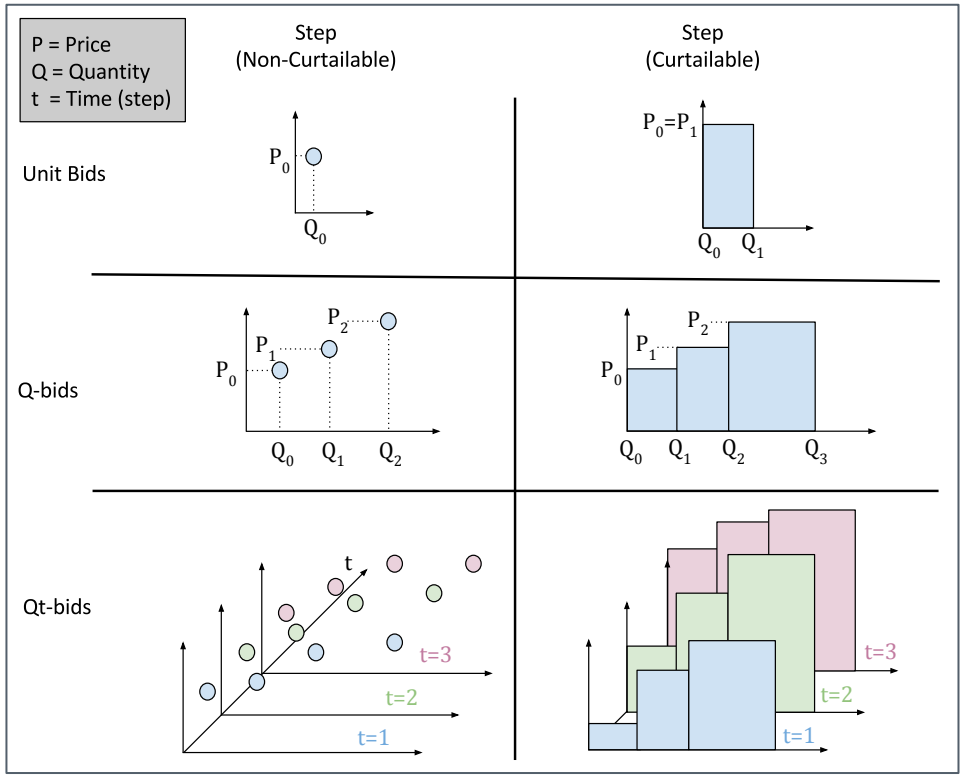


Bidding
Dimension

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)

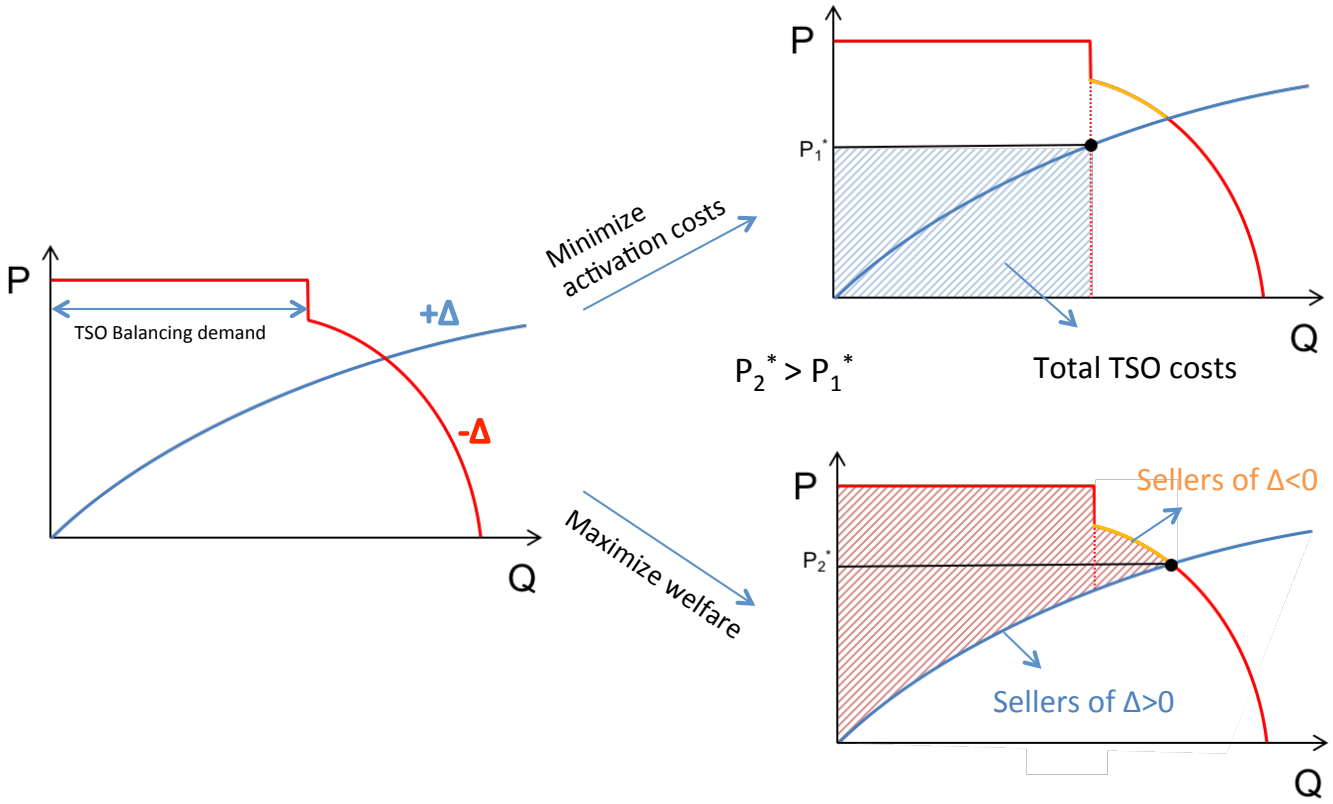
- **Accept-All-Time-Steps-or-None**: → Profile tracking
- **Ramping**: → Turbines
- **Max. number of activations**: → Avoiding wear & tear
- **Max. duration of activation**: → Air conditioning
- **Min. duration of activation**: → Plant efficiency
- **Min. delay between activations**: → Avoiding wear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

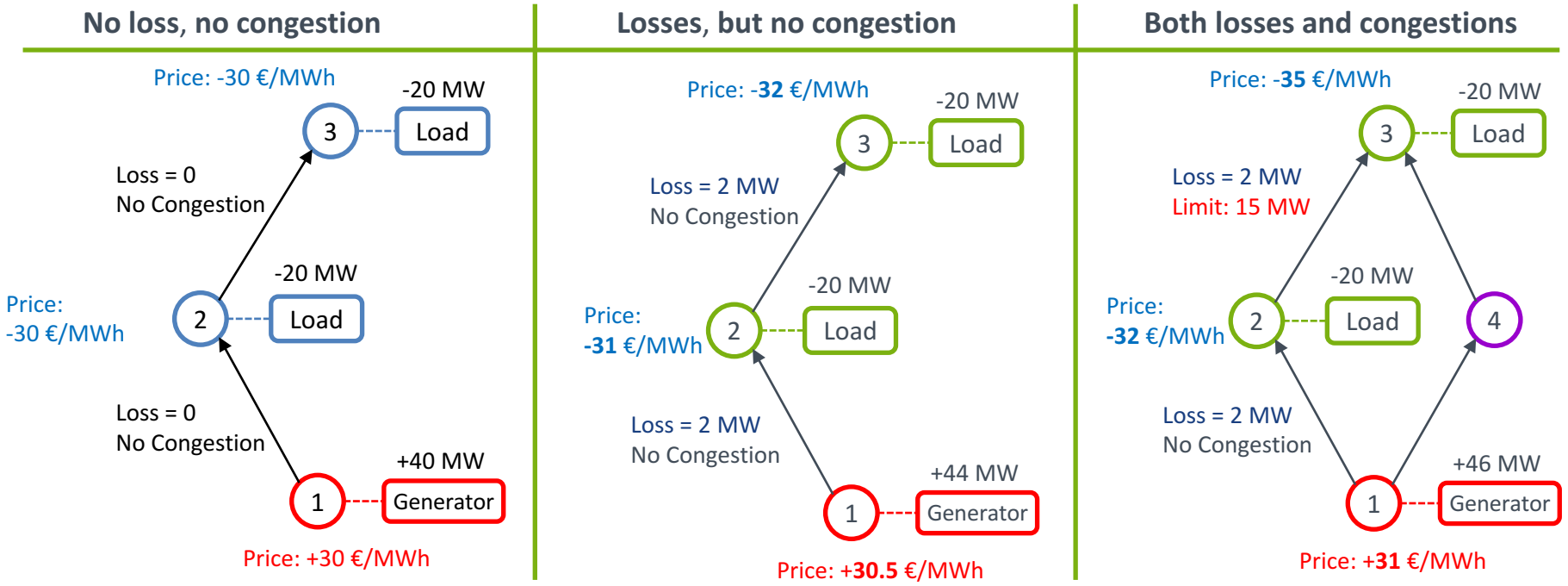


Pricing
Dimension

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



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TSO-DSO CS-dependent
Timing Dimension

CS A: Centralized AS market

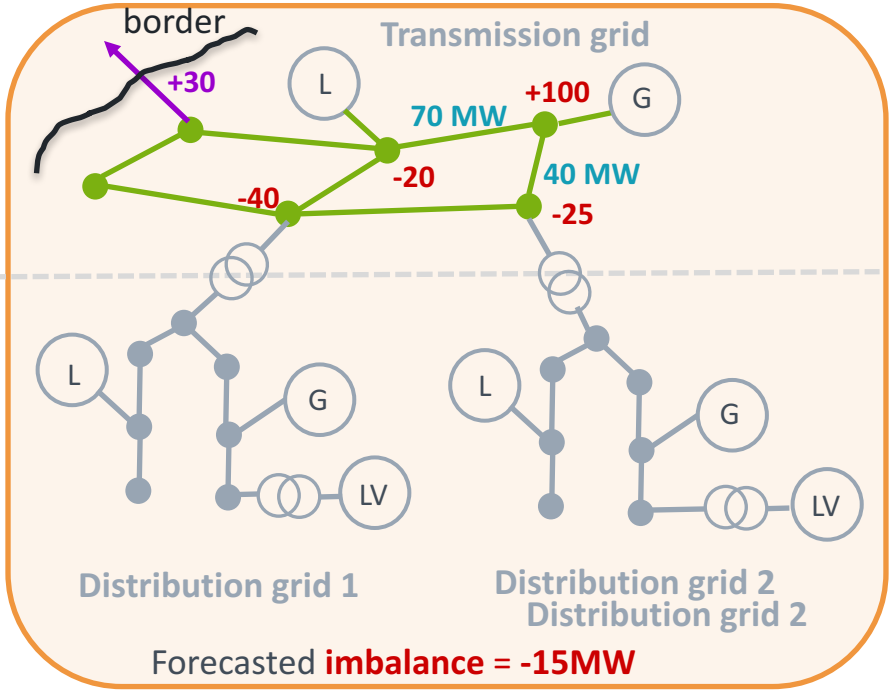
Net power injection at node i =
Sum of power **generated** at node i
- Sum of power **consumed** at node i

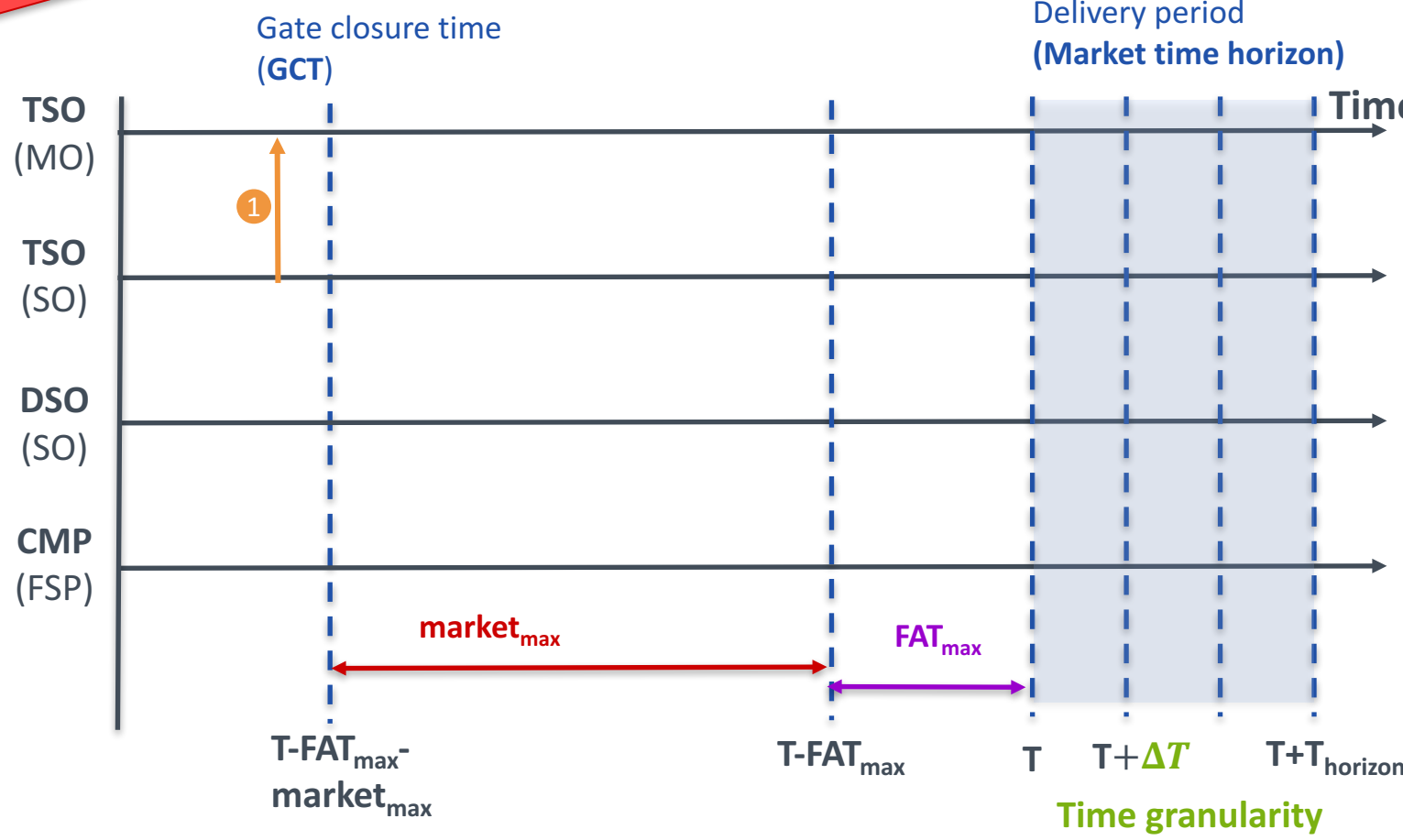
Market$_{max}$ = Max time allowed for market algorithm (+pre/post-processing)

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
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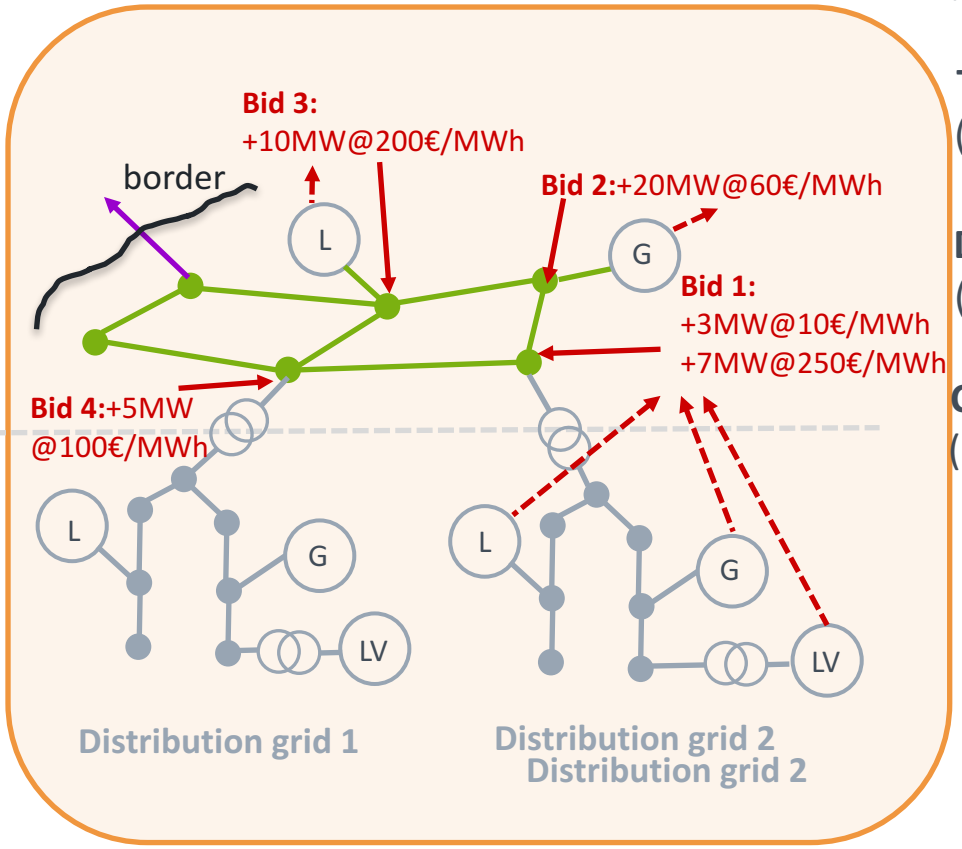
CS A: Centralized AS market

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



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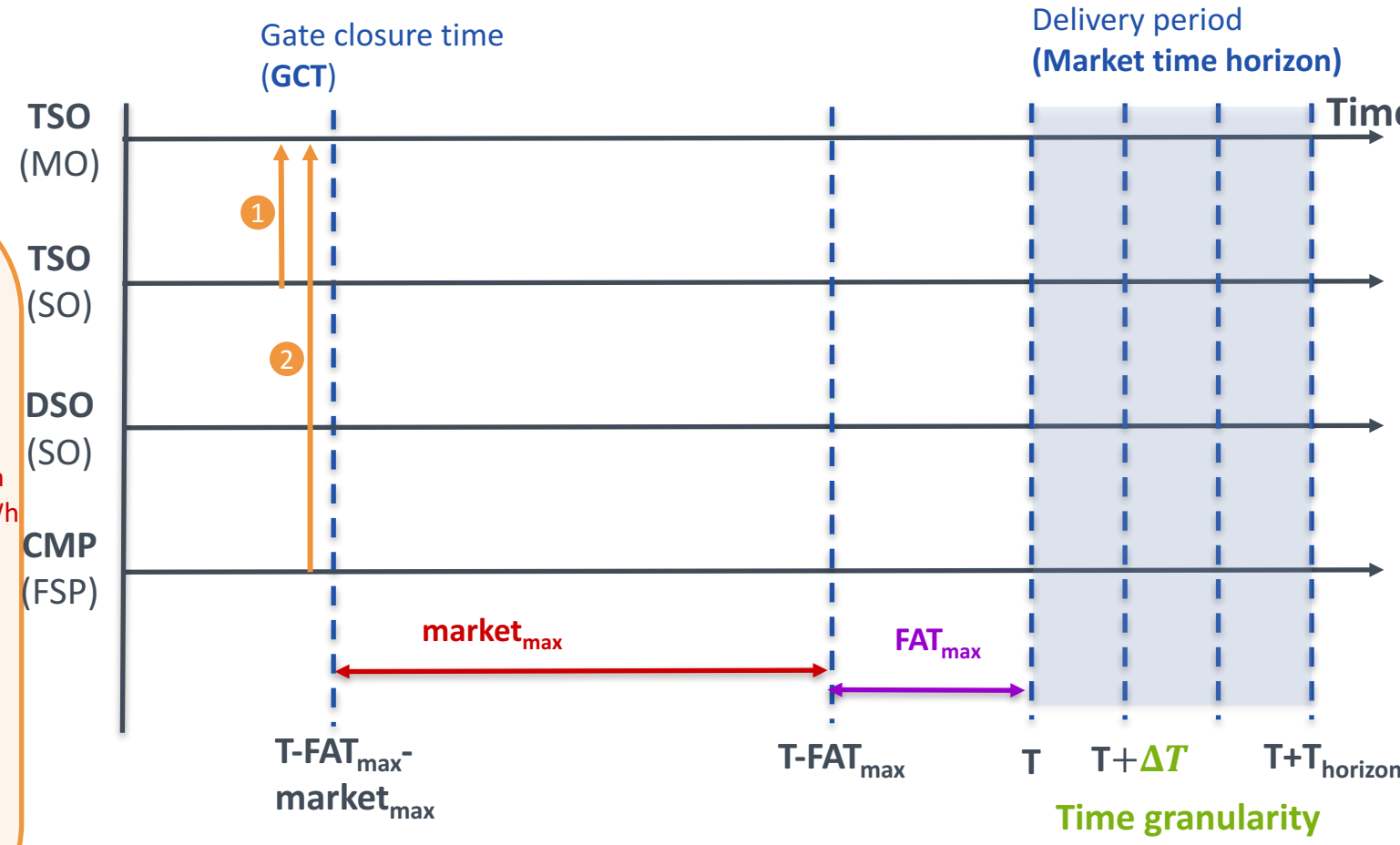

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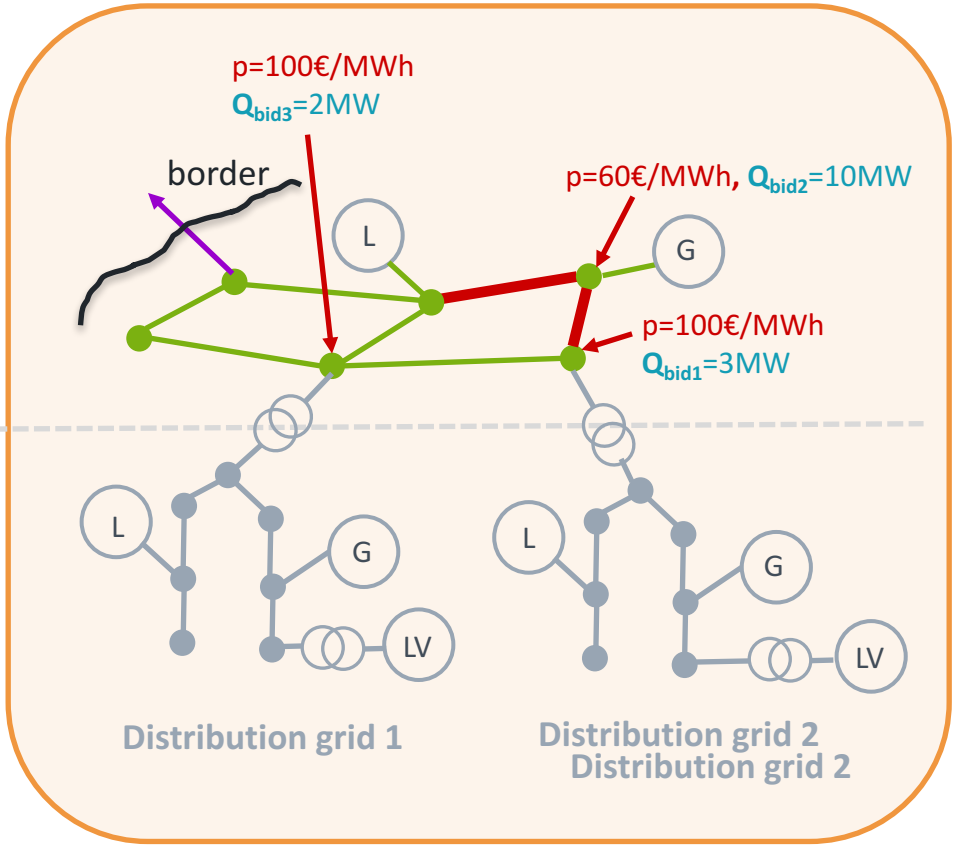
3 MO **runs** the **market clearing algorithm**: it computes the accepted bid **quantities** and **nodal** marginal **price**.



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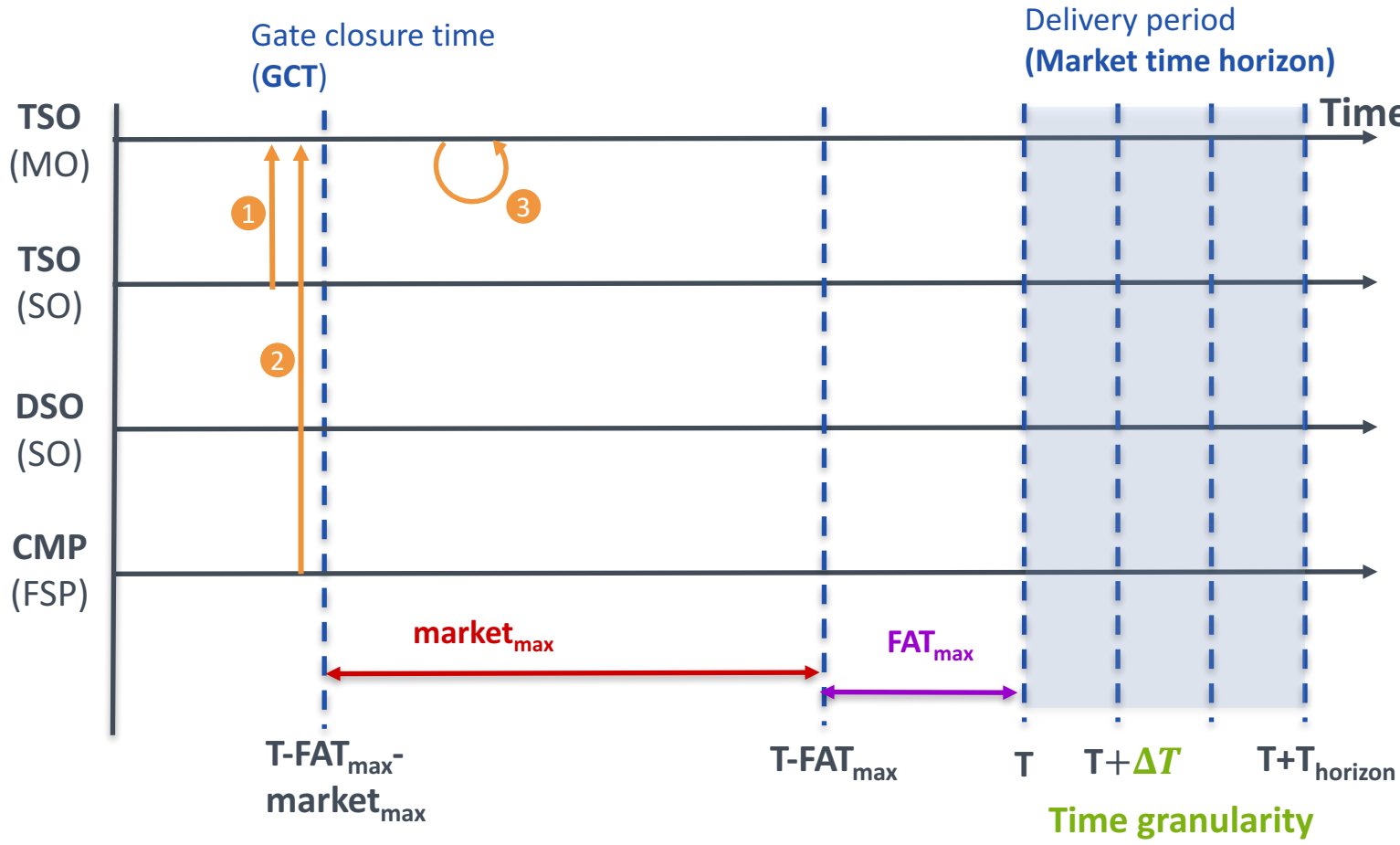

TSO-DSO CS-dependent
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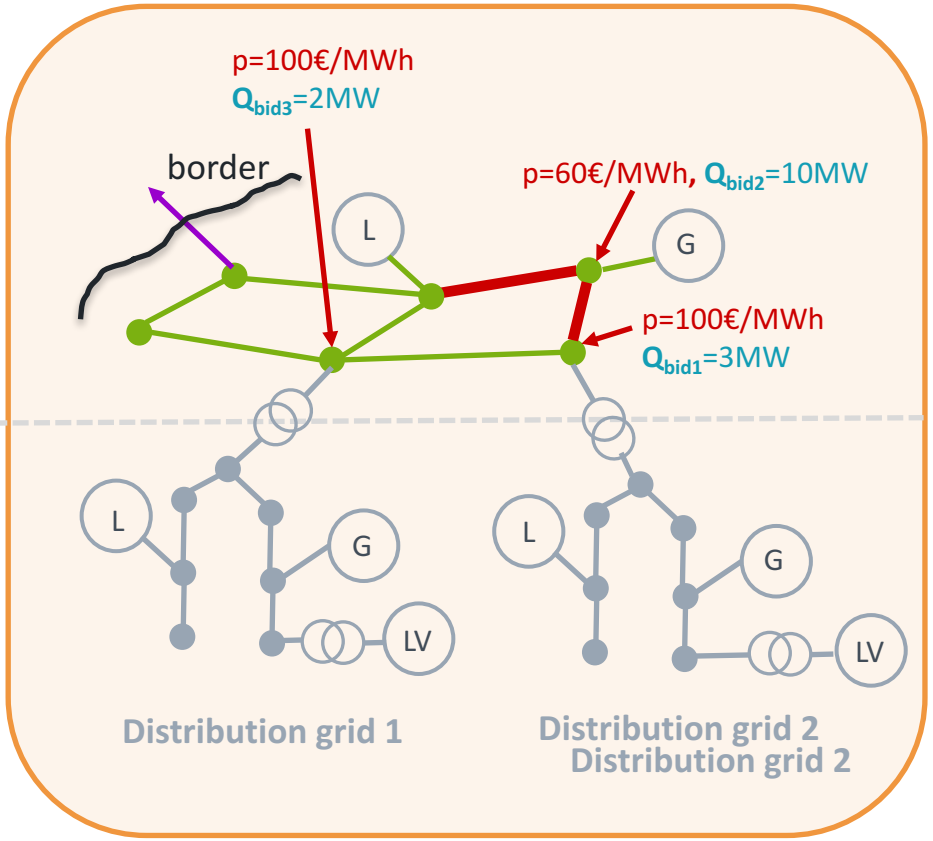
CS A: Centralized AS market

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



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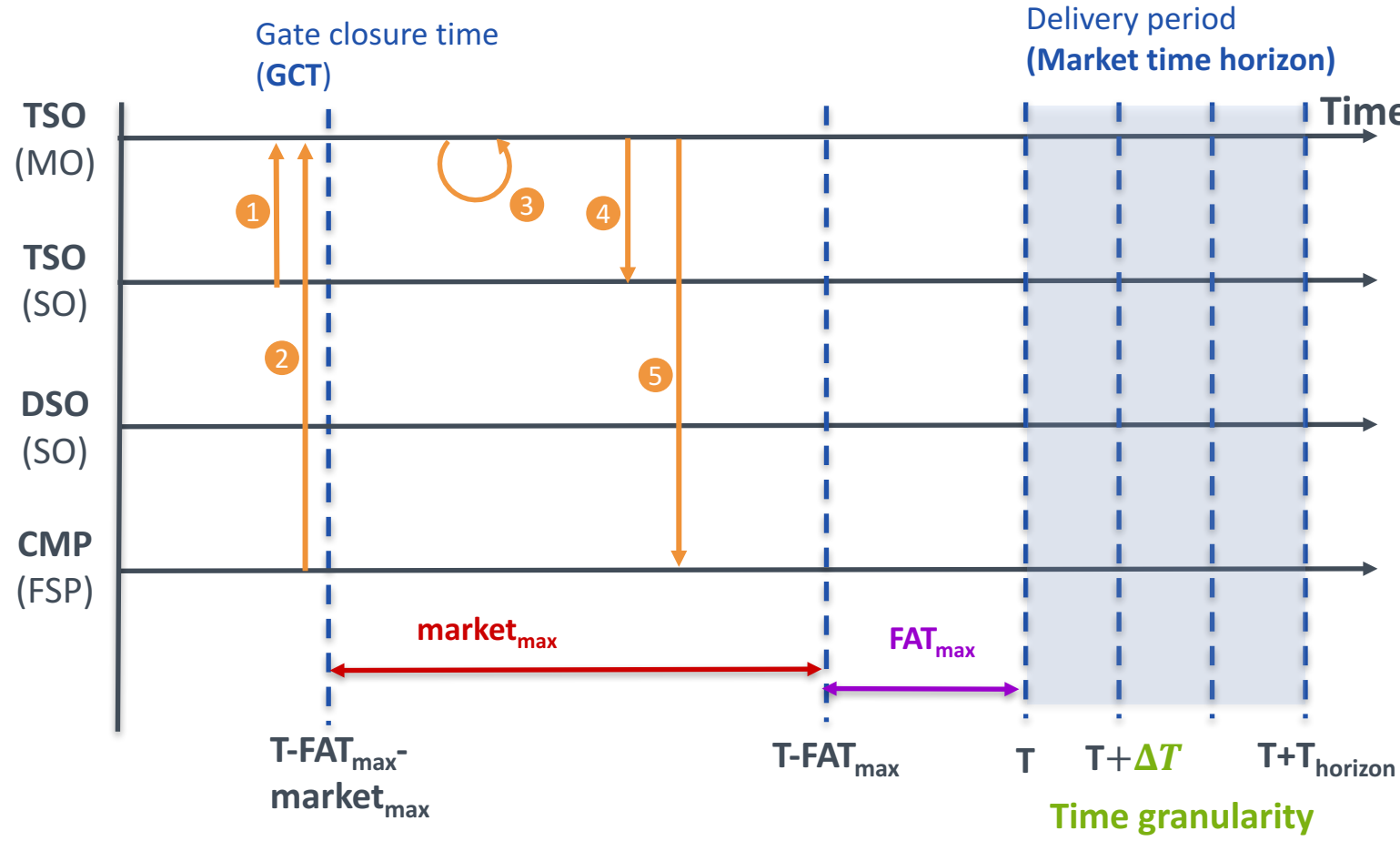

TSO-DSO CS-dependent
Timing Dimension

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

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

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

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)
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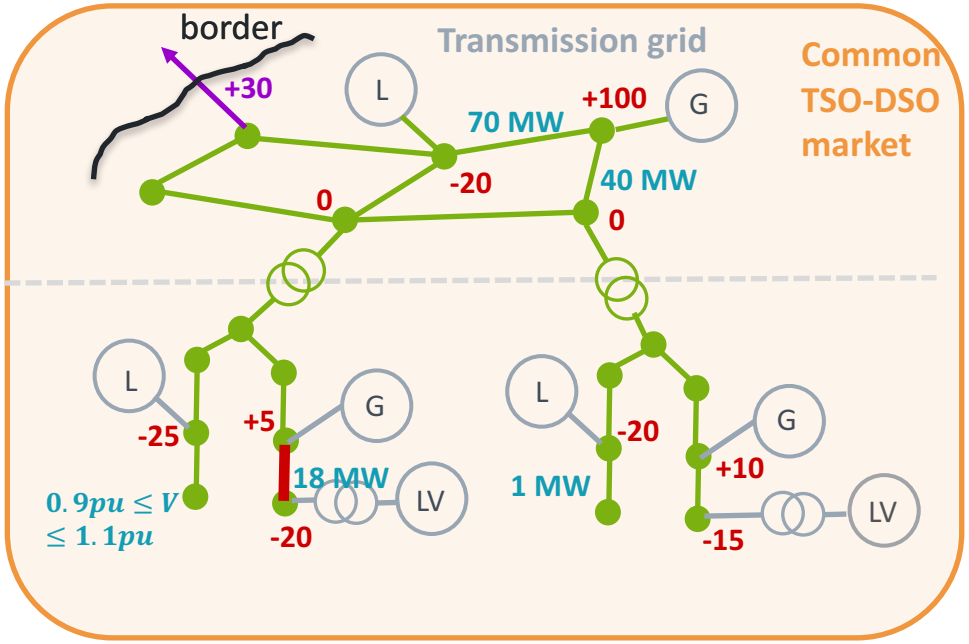
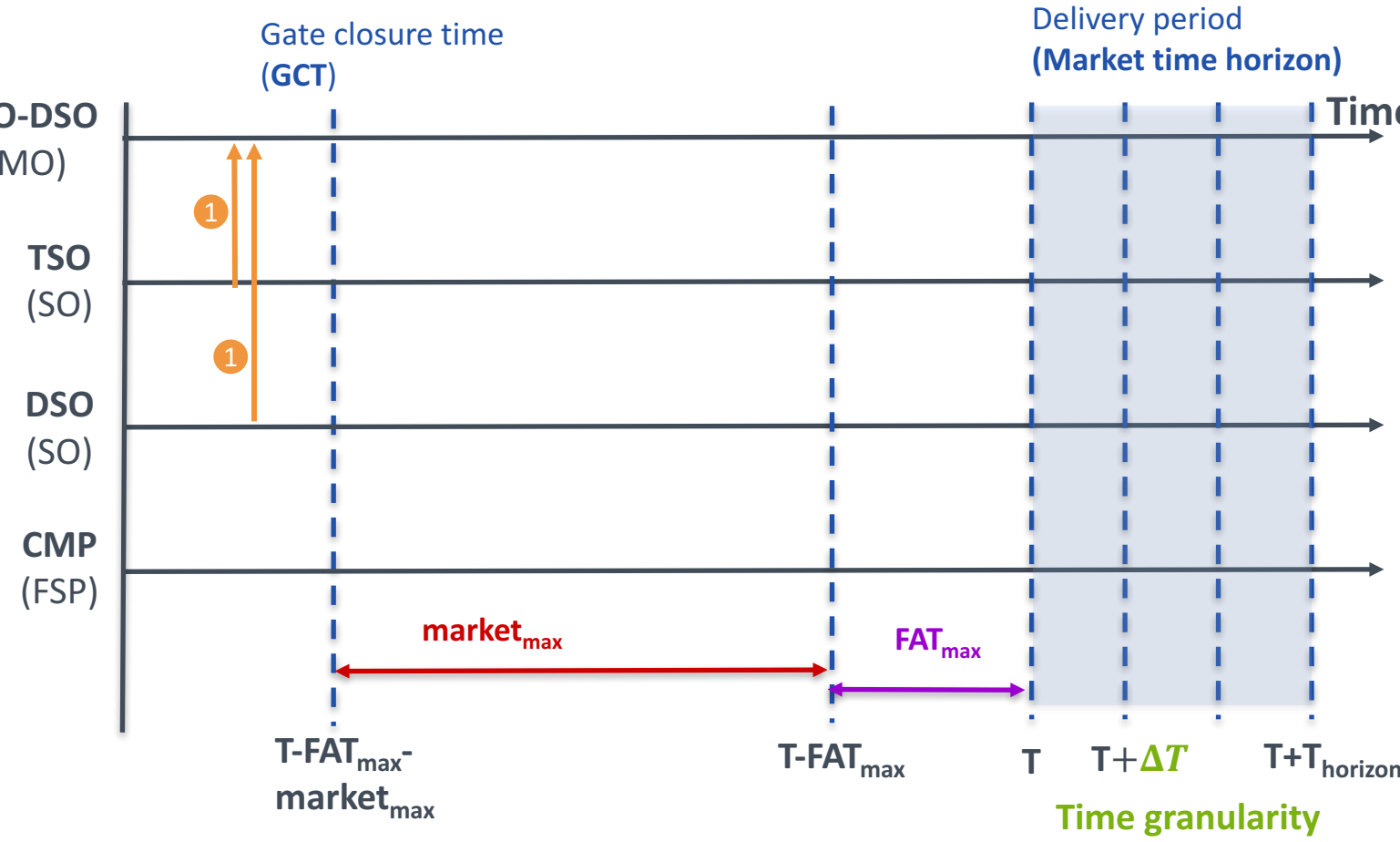


Forecasted **imbalance** = **-15MW**

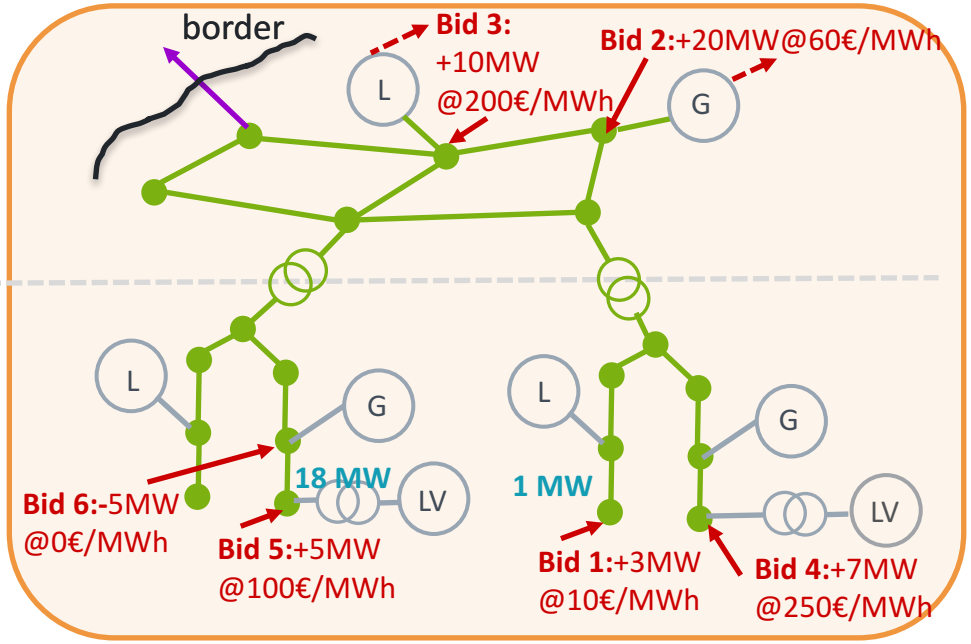


TSO-DSO CS-dependent
Timing Dimension

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)

Common TSO-DSO market



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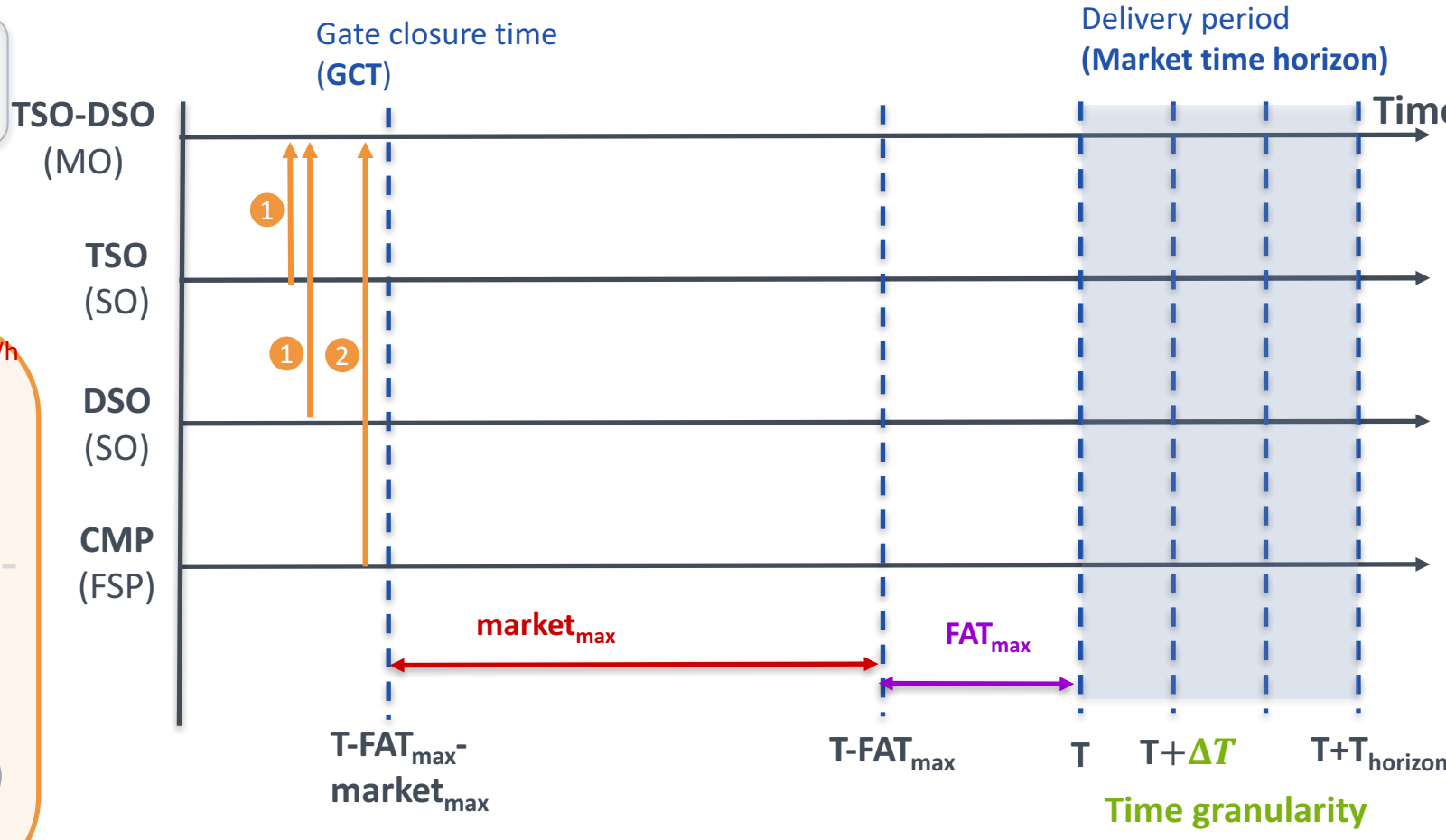

TSO-DSO CS-dependent
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CS D1: Common TSO-DSO AS market (centralized)

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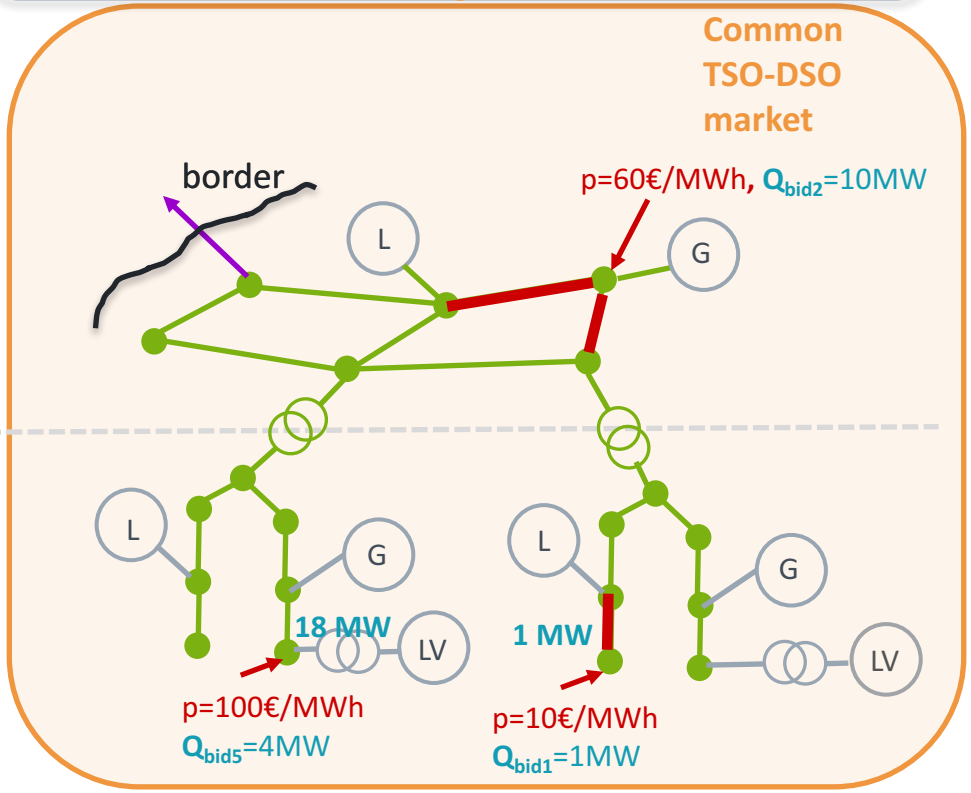

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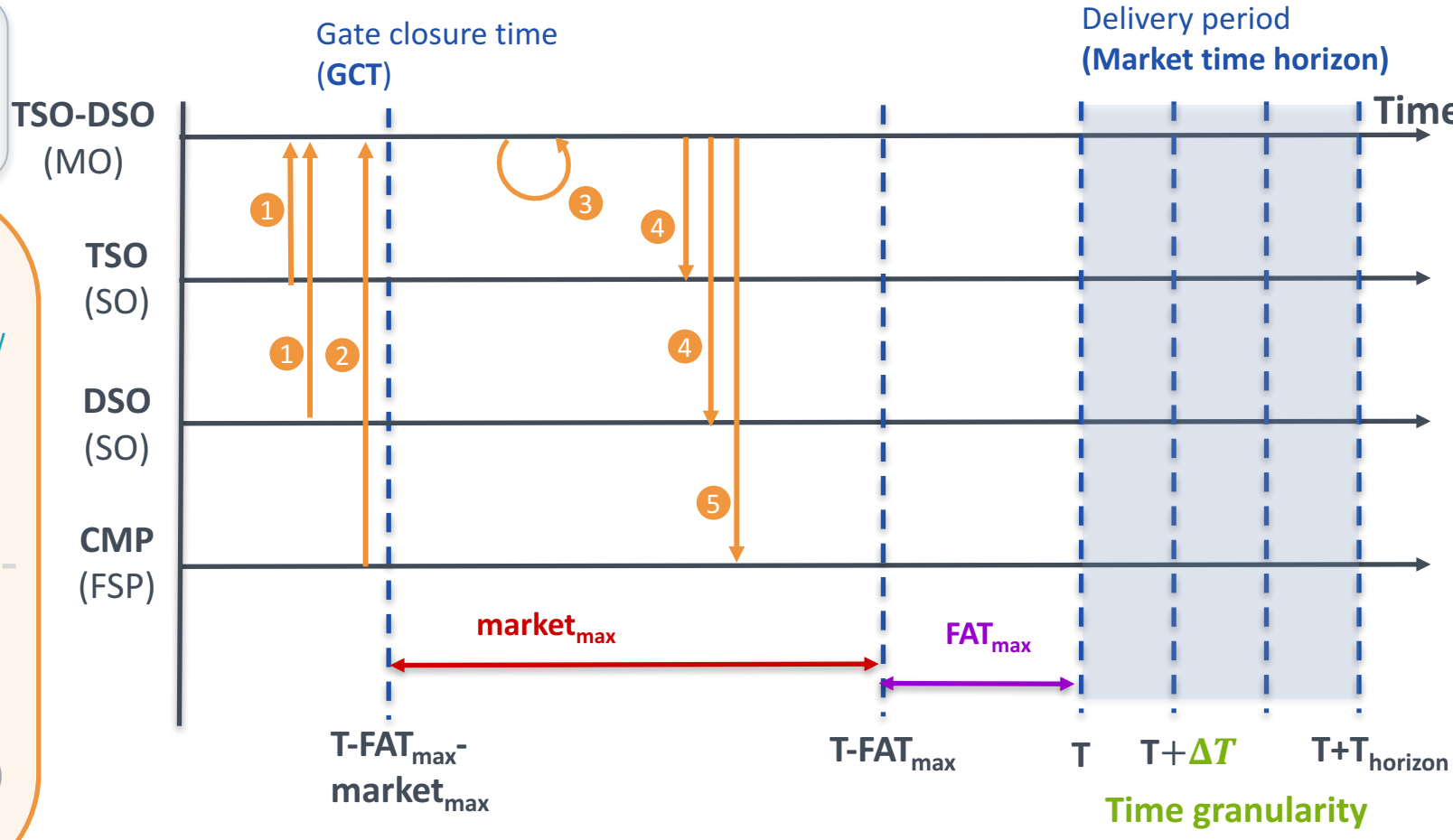
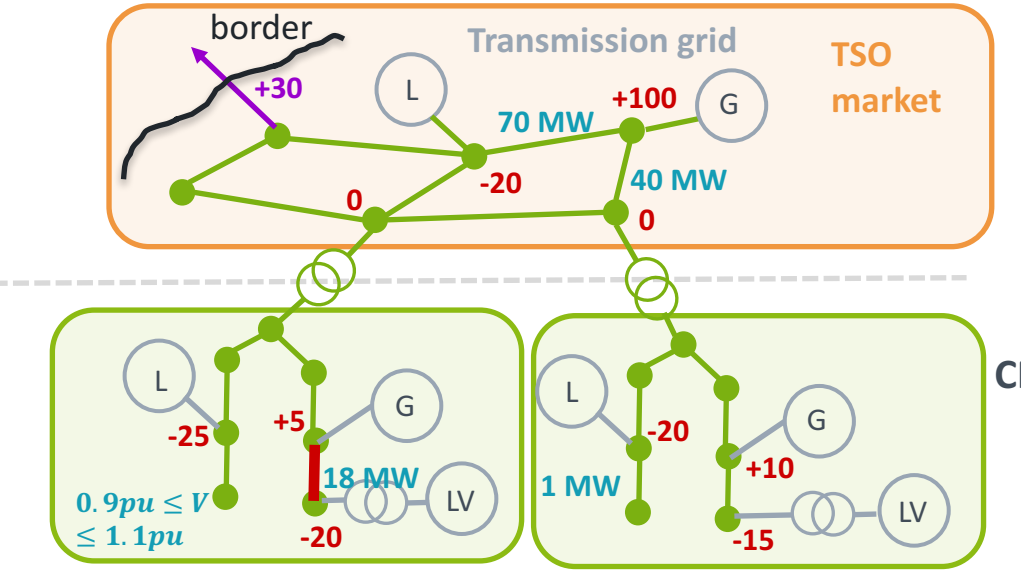


TSO-DSO CS-dependent
Timing Dimension

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**



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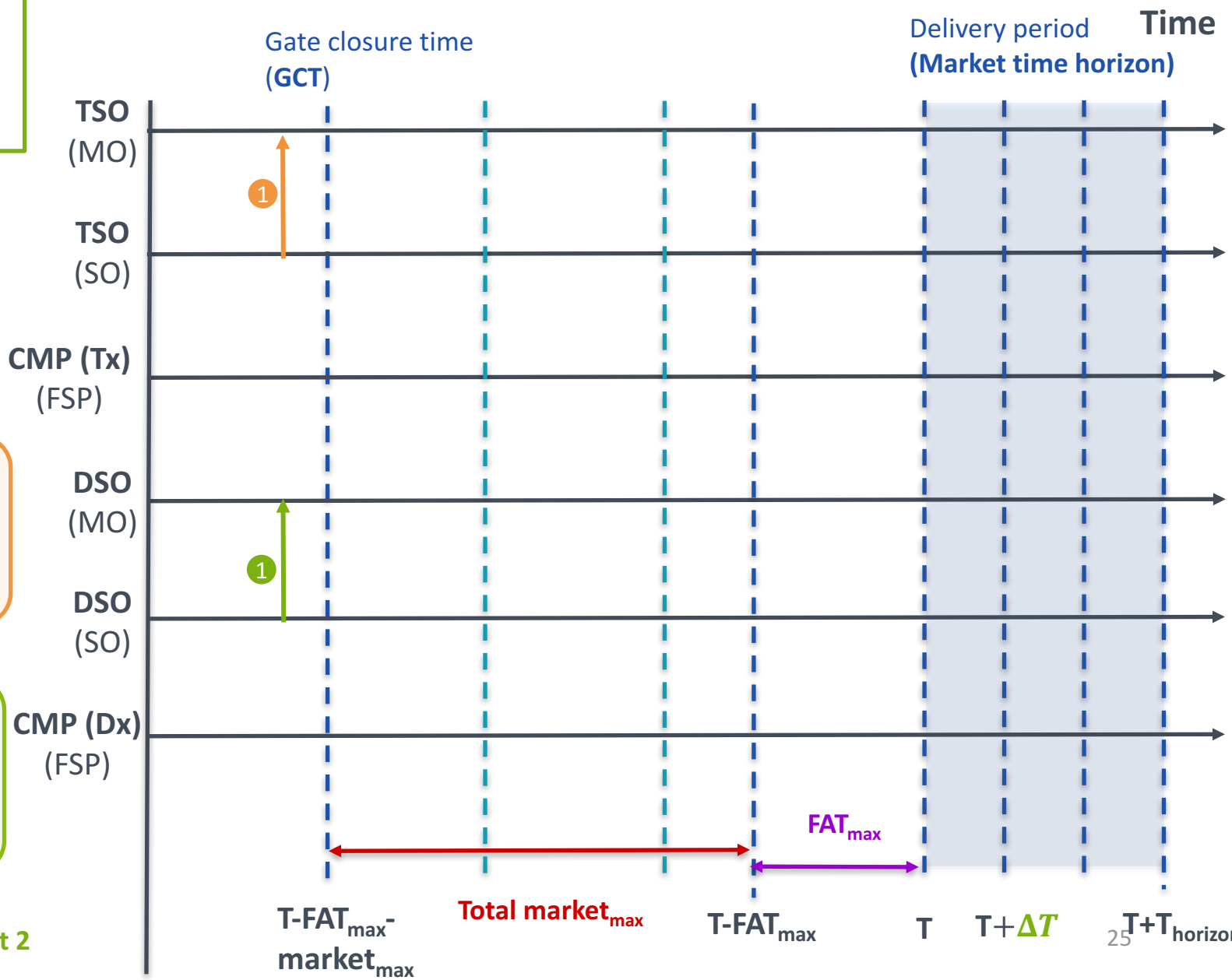
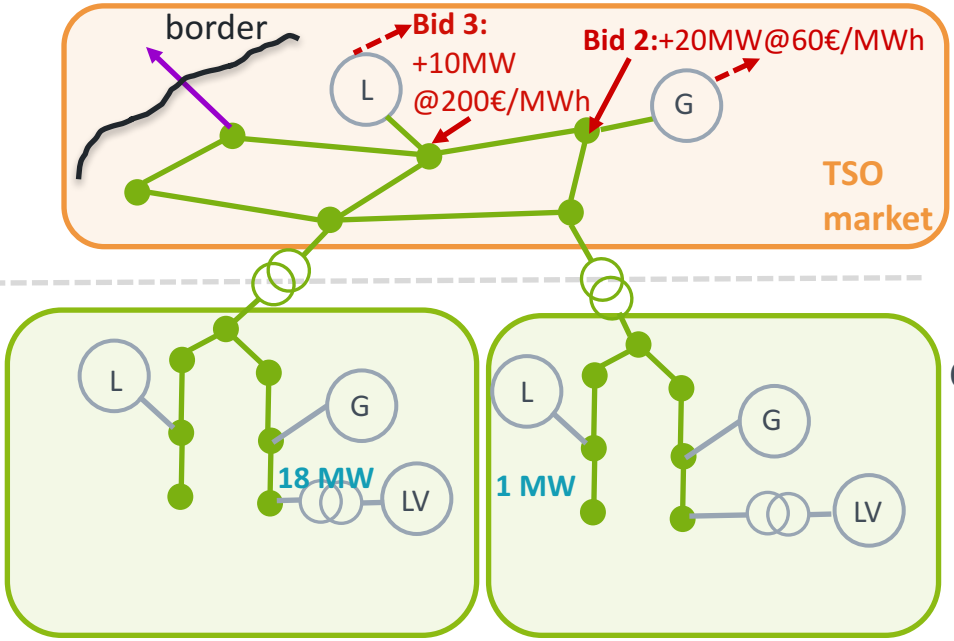
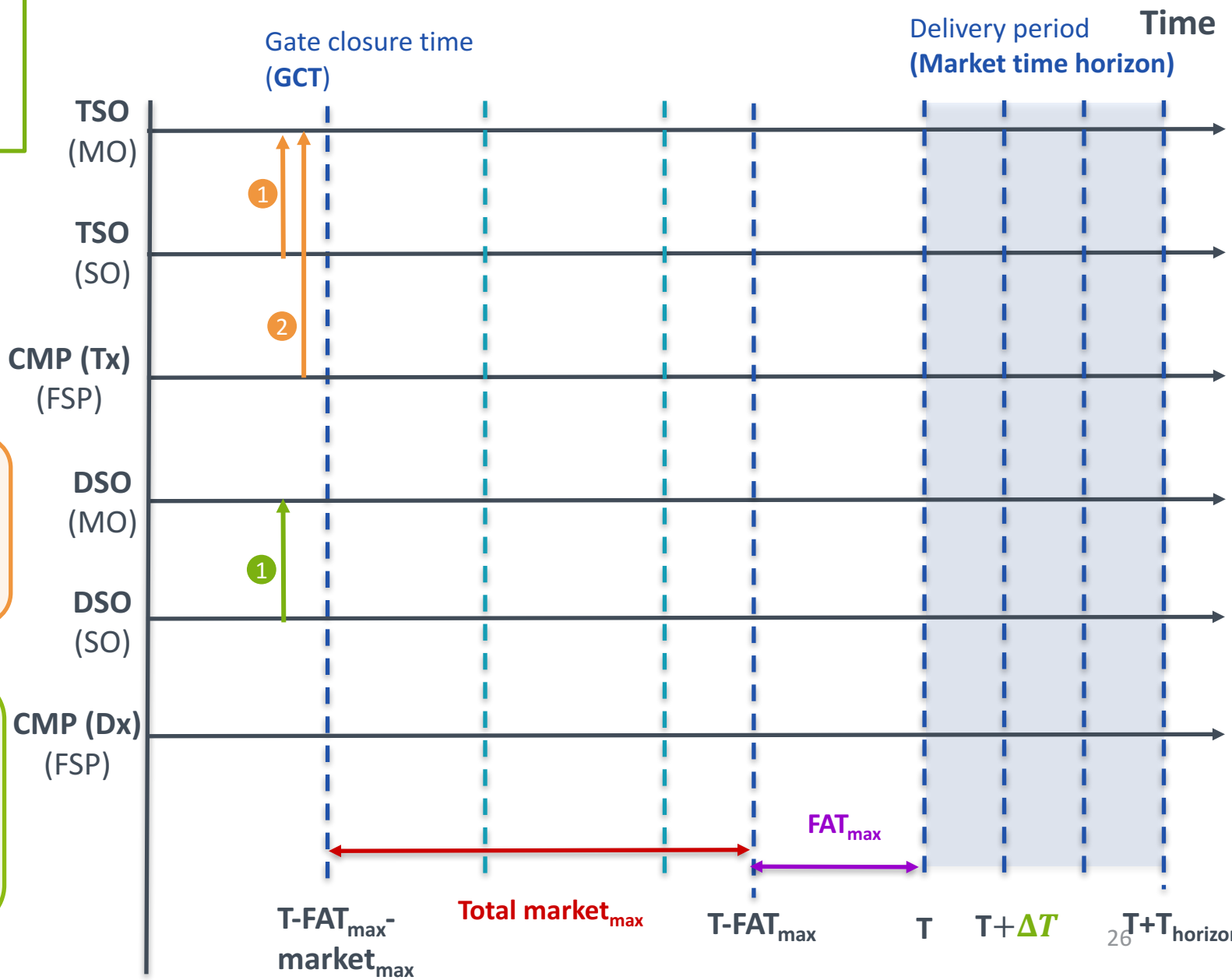


TSO-DSO CS-dependent
Timing Dimension

CS B: Local AS market

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

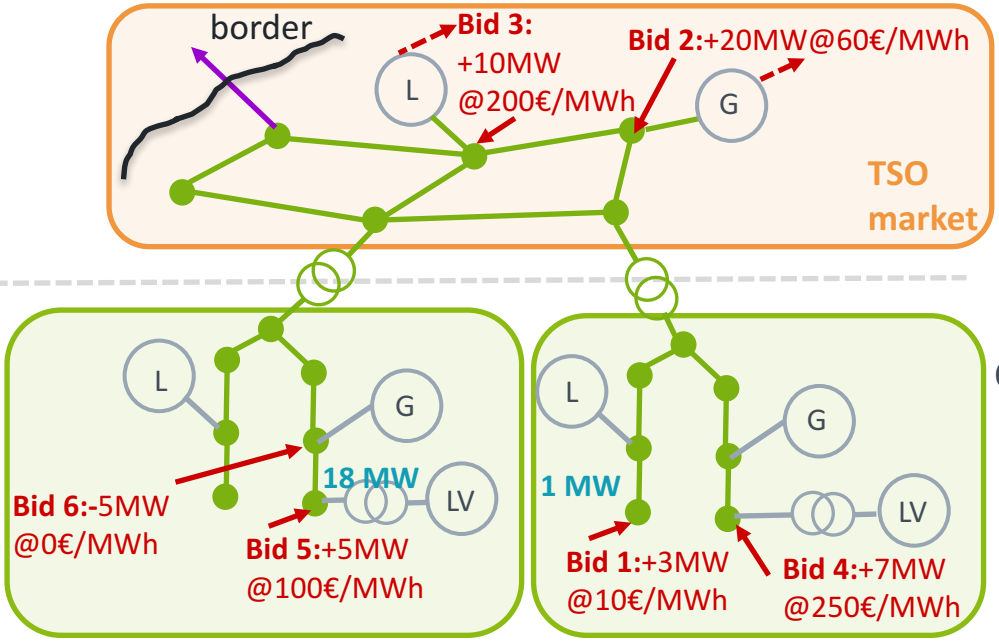


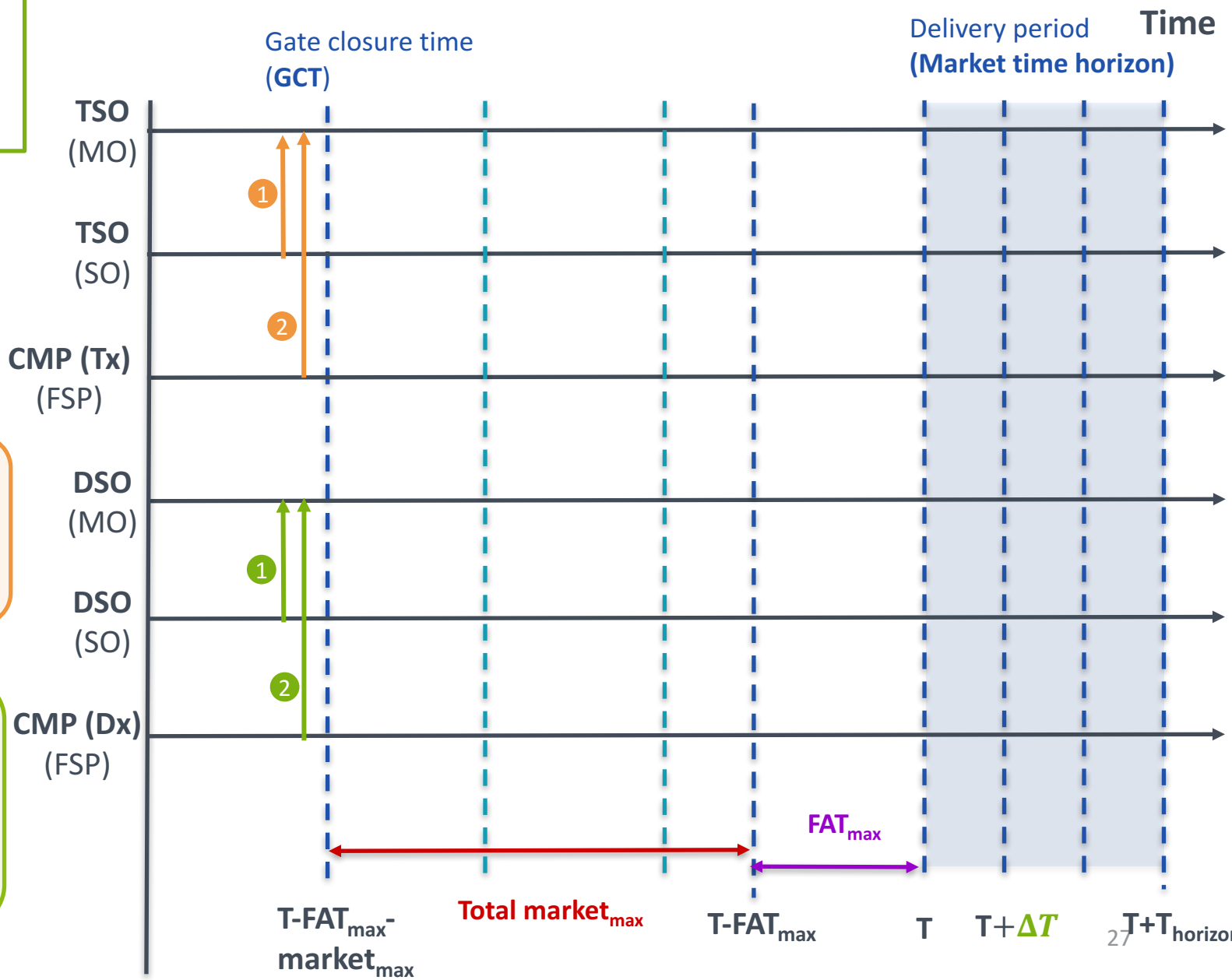


TSO-DSO CS-dependent
Timing Dimension

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)**

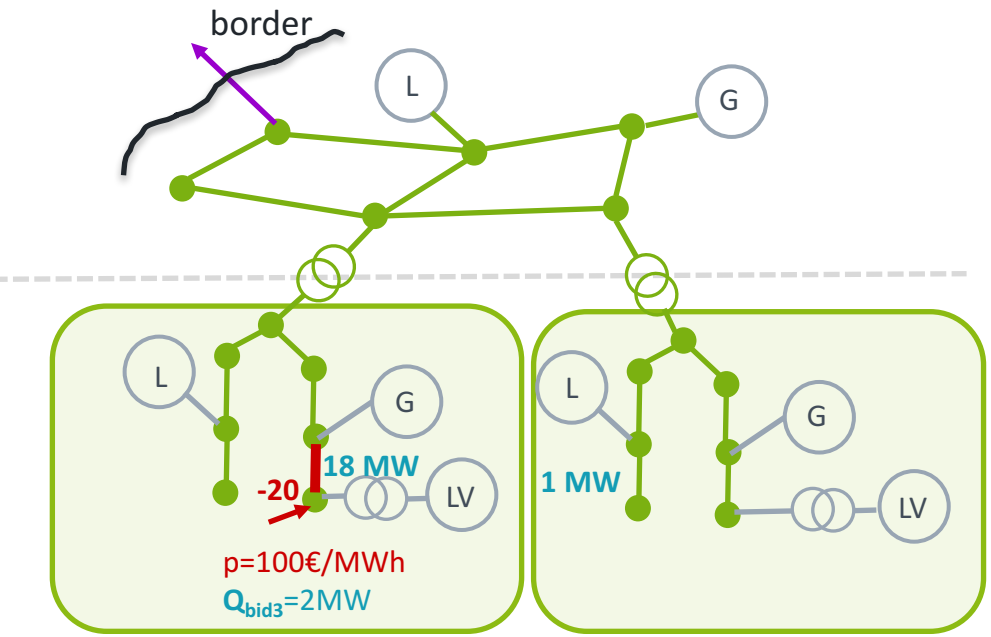


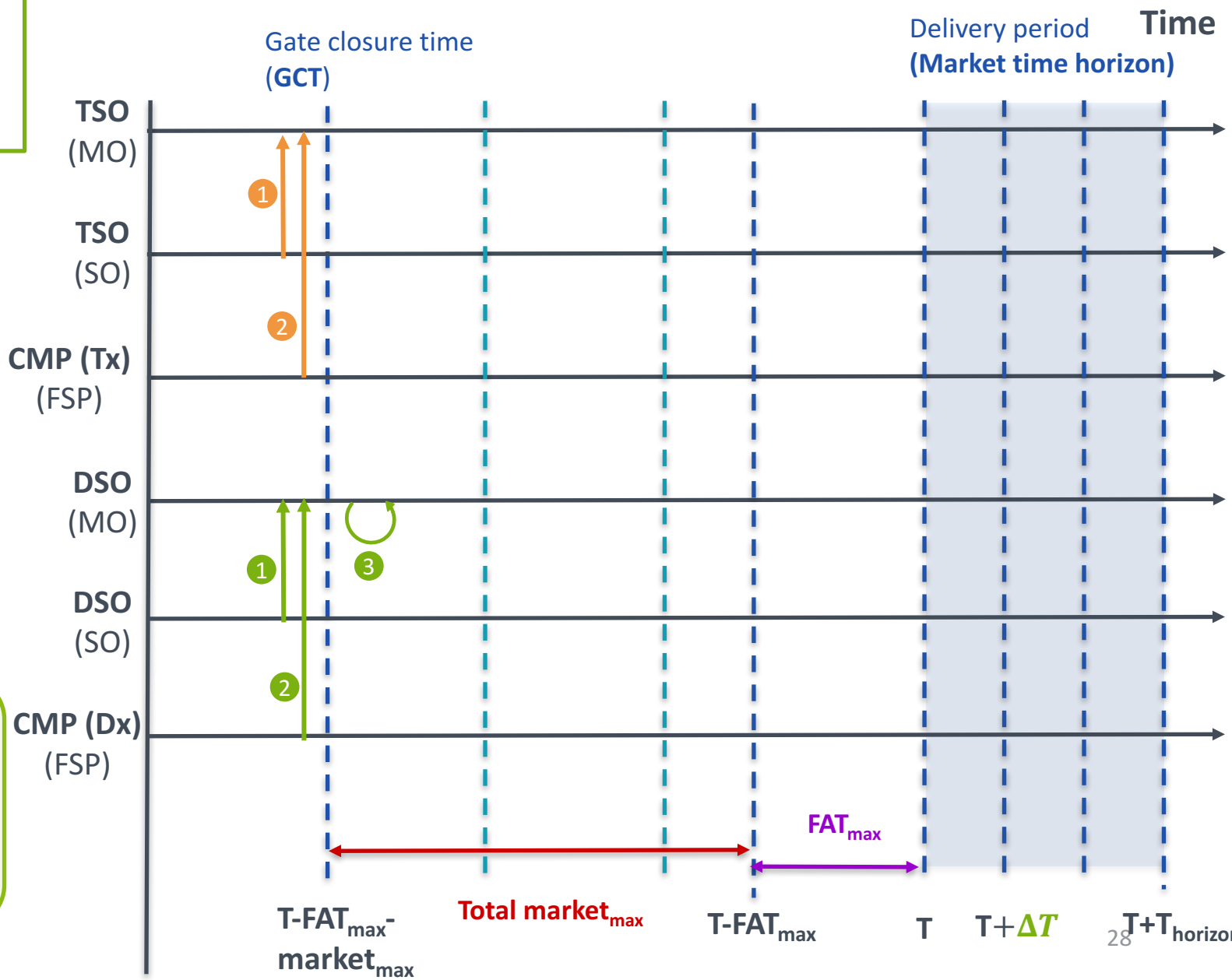


TSO-DSO CS-dependent
Timing Dimension

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.





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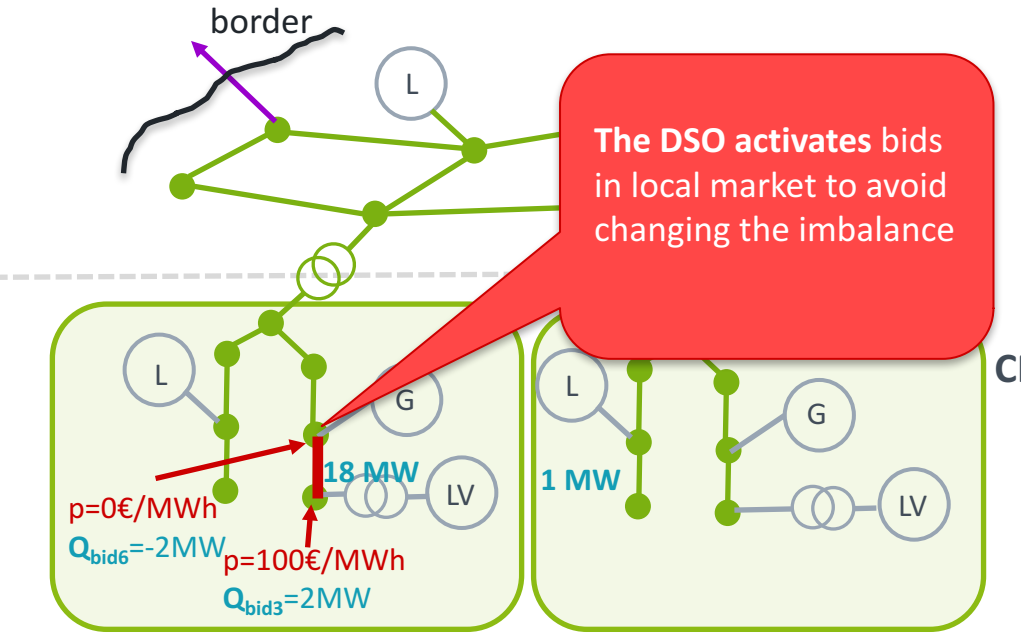
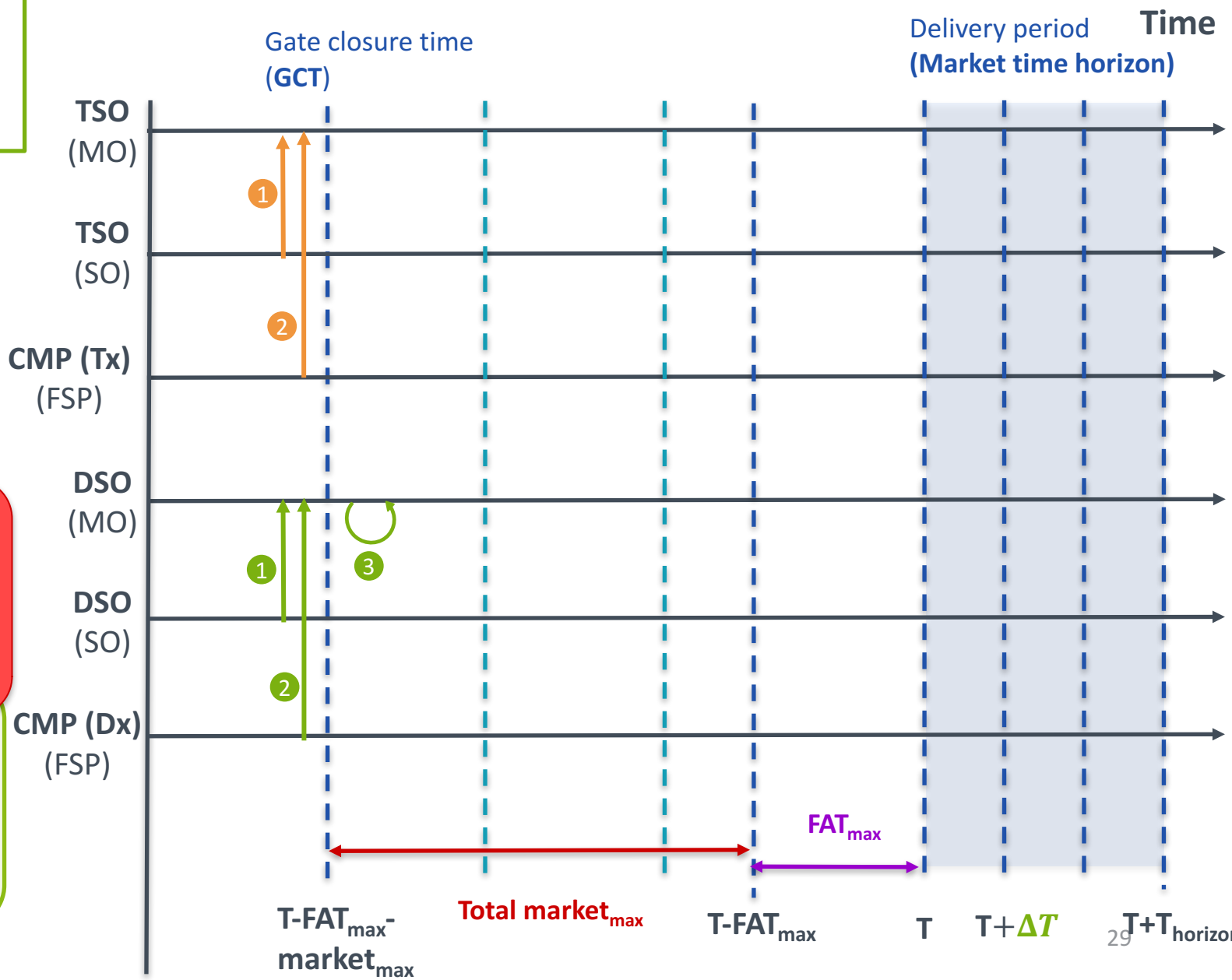
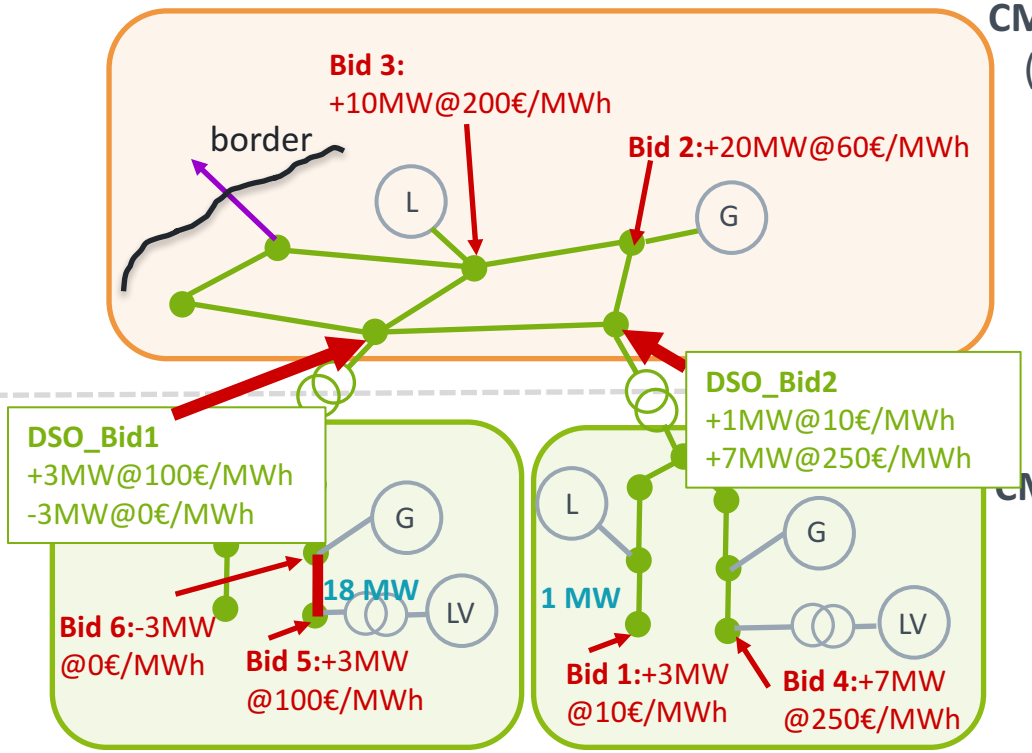


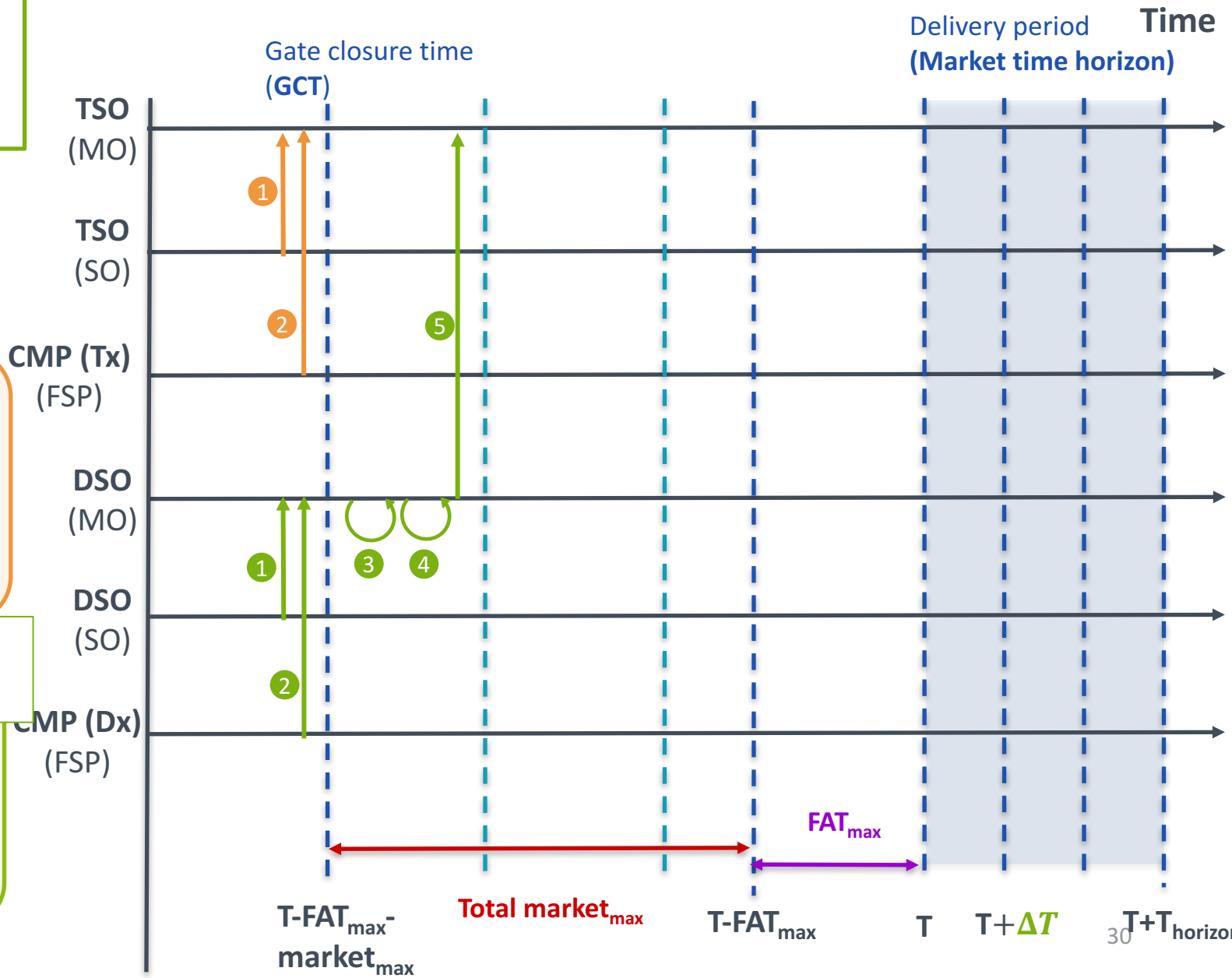


TSO-DSO CS-dependent
Timing Dimension

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}**

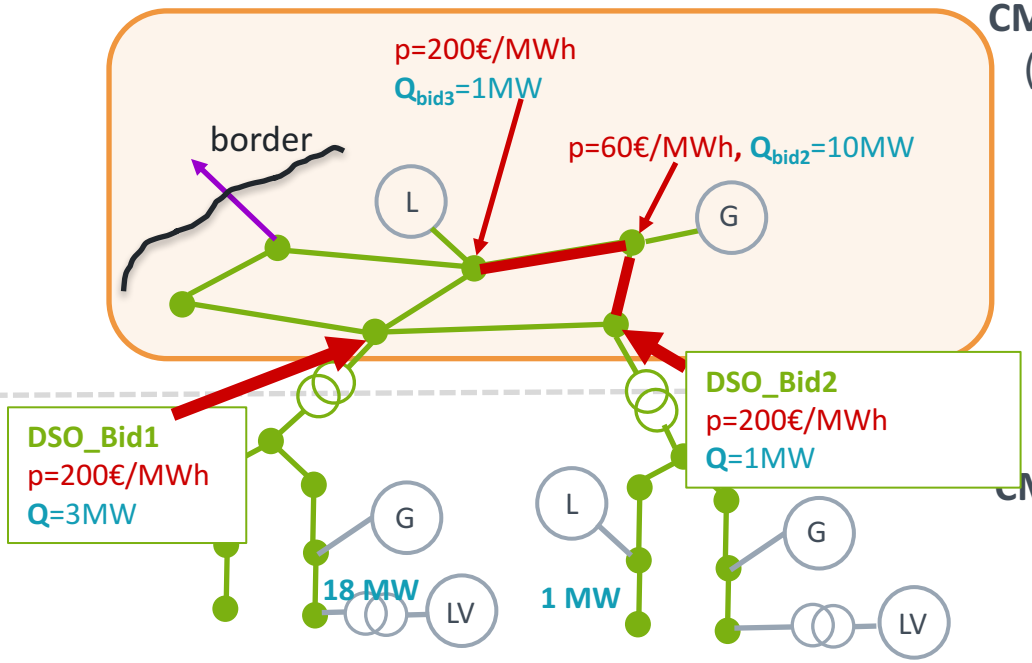


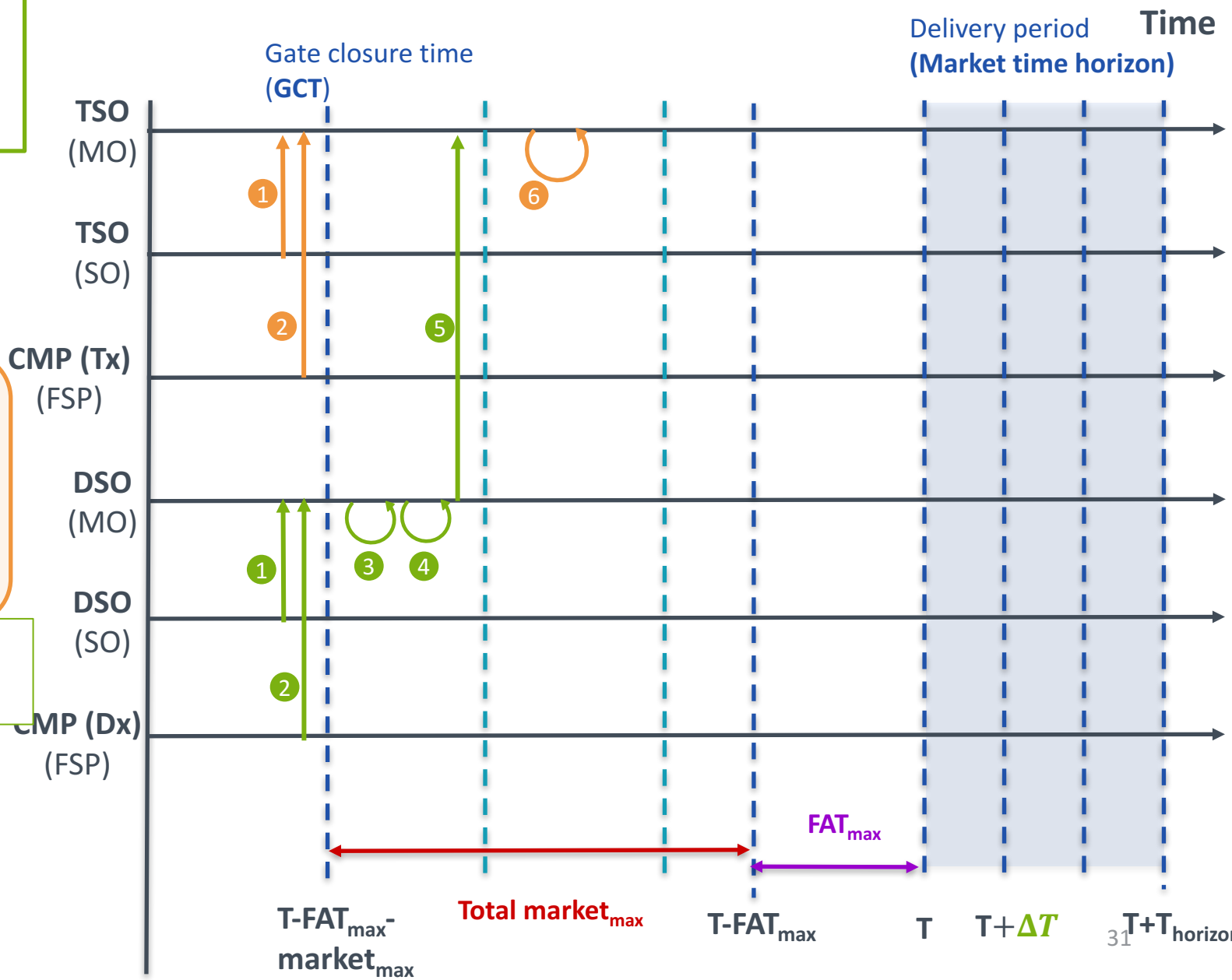


TSO-DSO CS-dependent
Timing Dimension

CS B: Local AS market

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

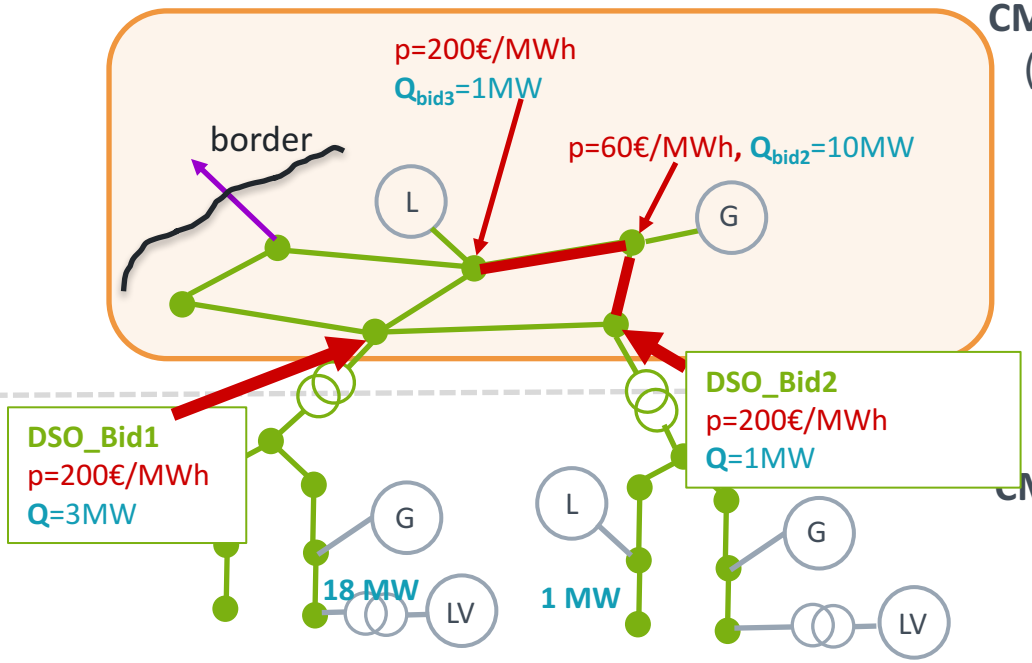


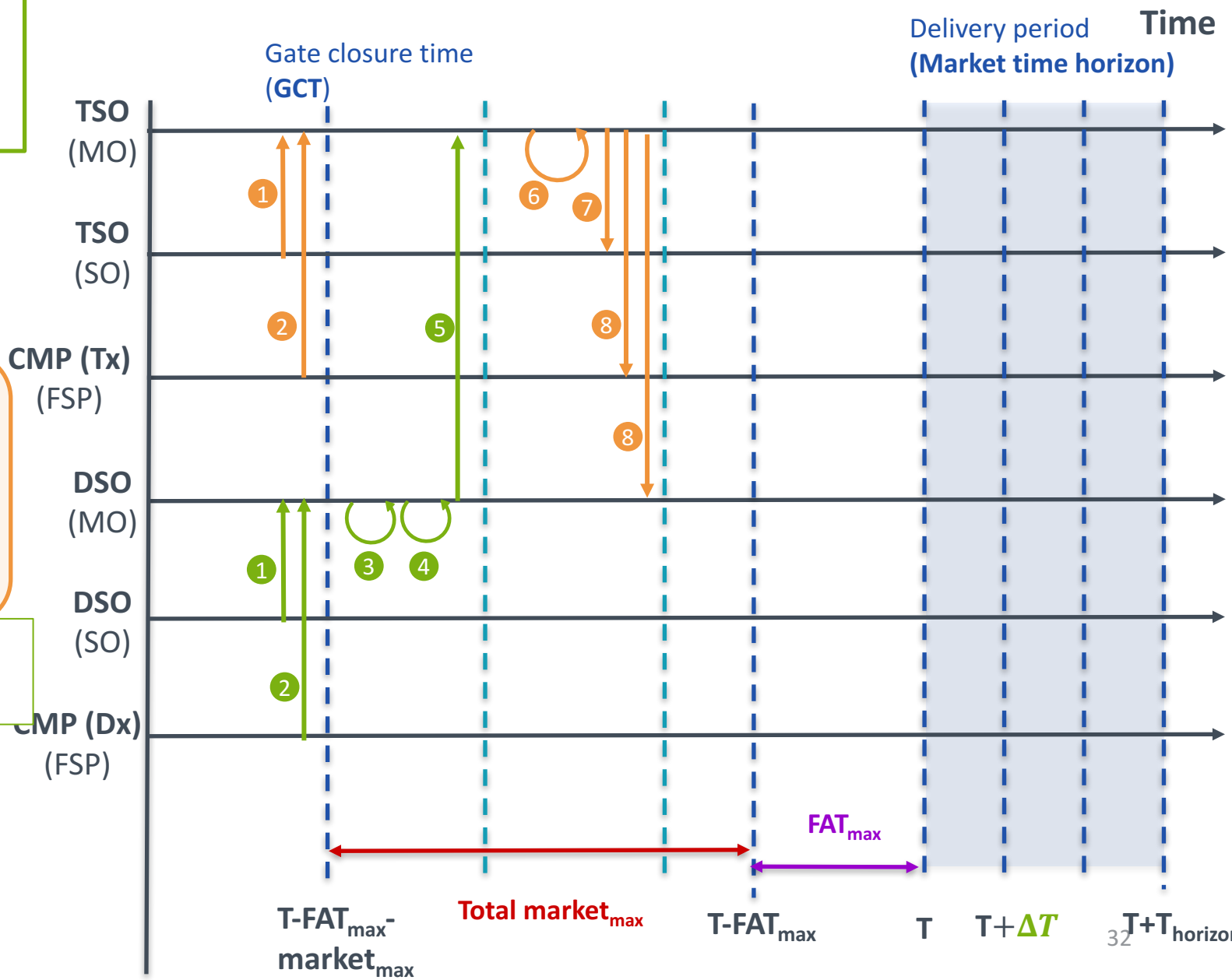


TSO-DSO CS-dependent
Timing Dimension

CS B: Local AS market

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

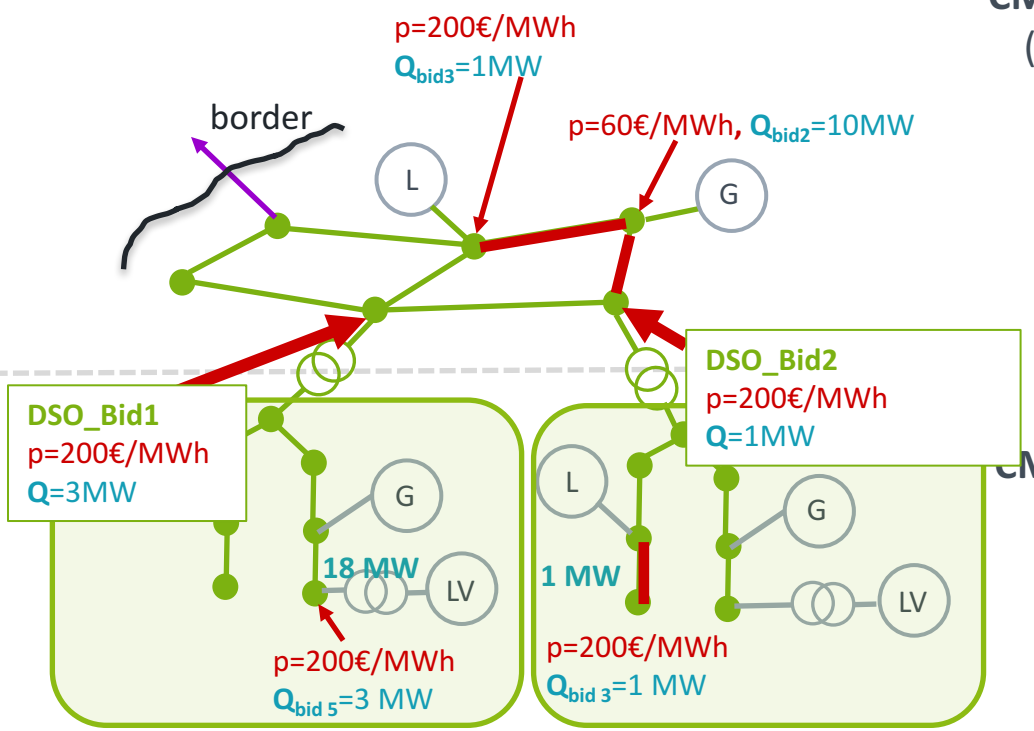


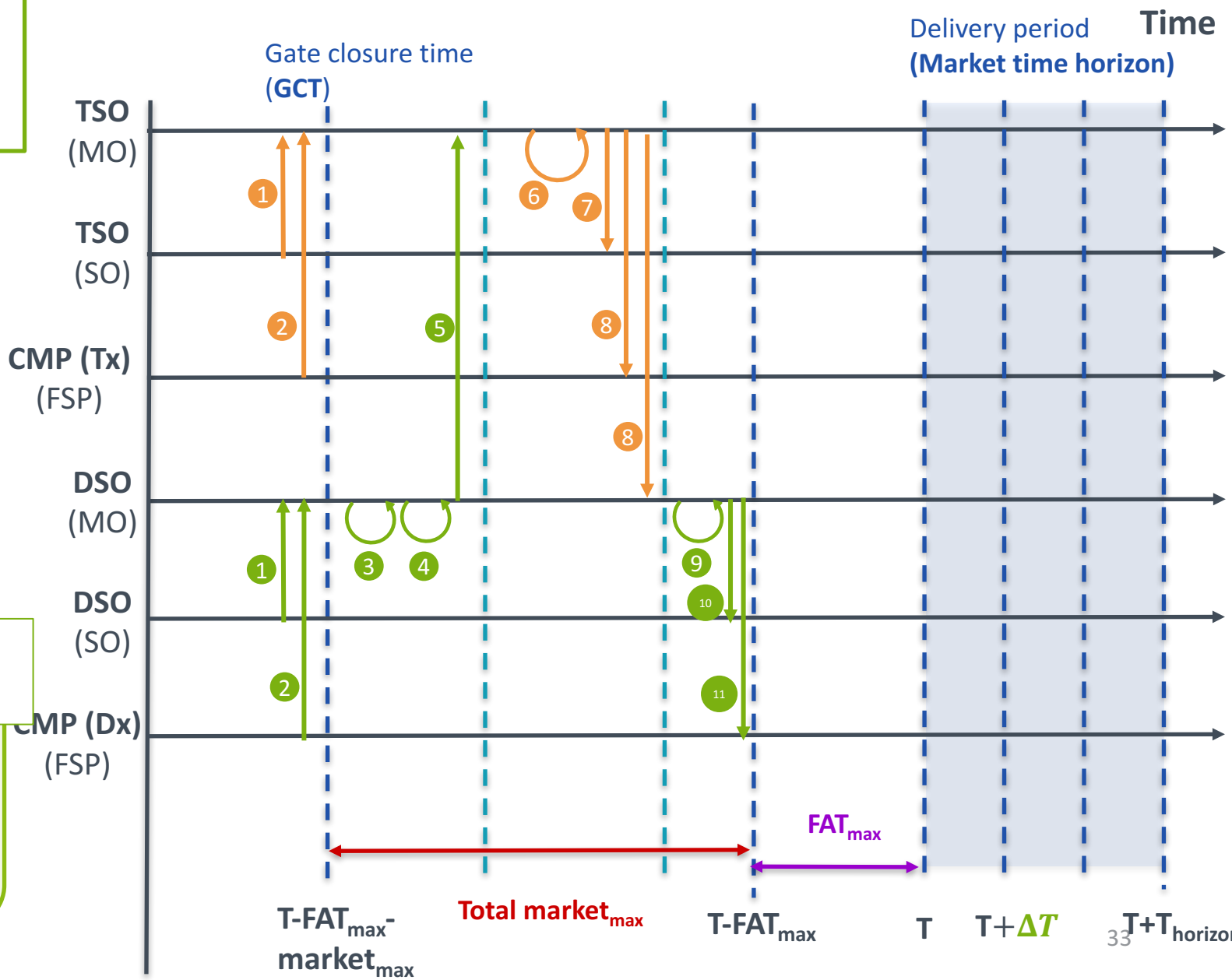


TSO-DSO CS-dependent
Timing Dimension

CS B: Local AS market

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



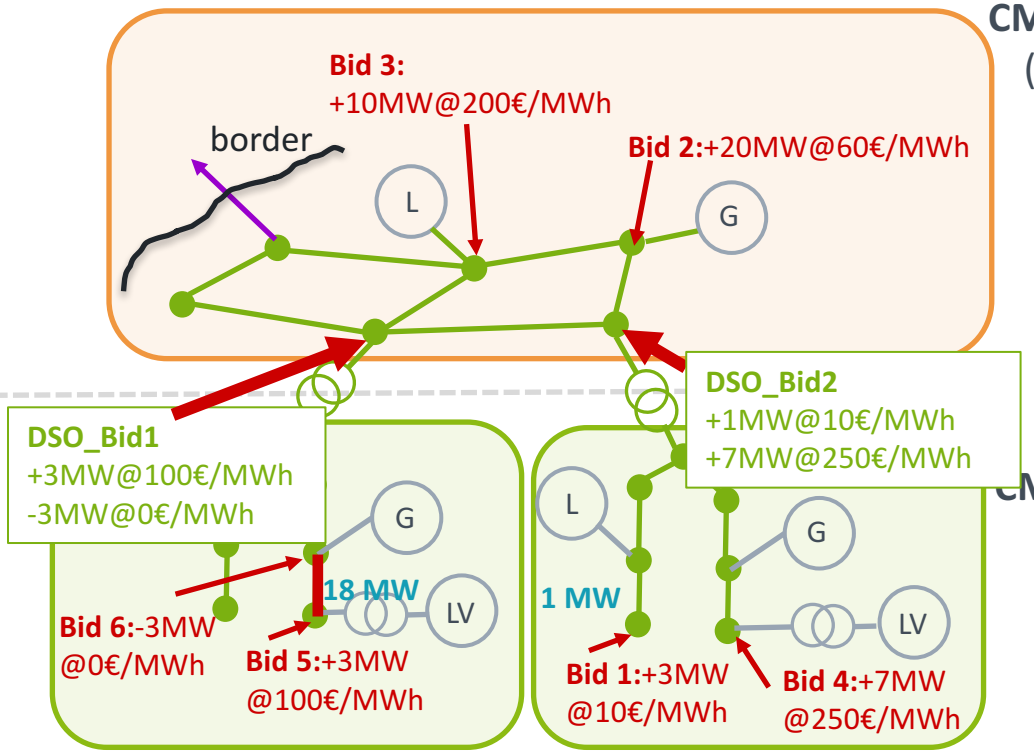


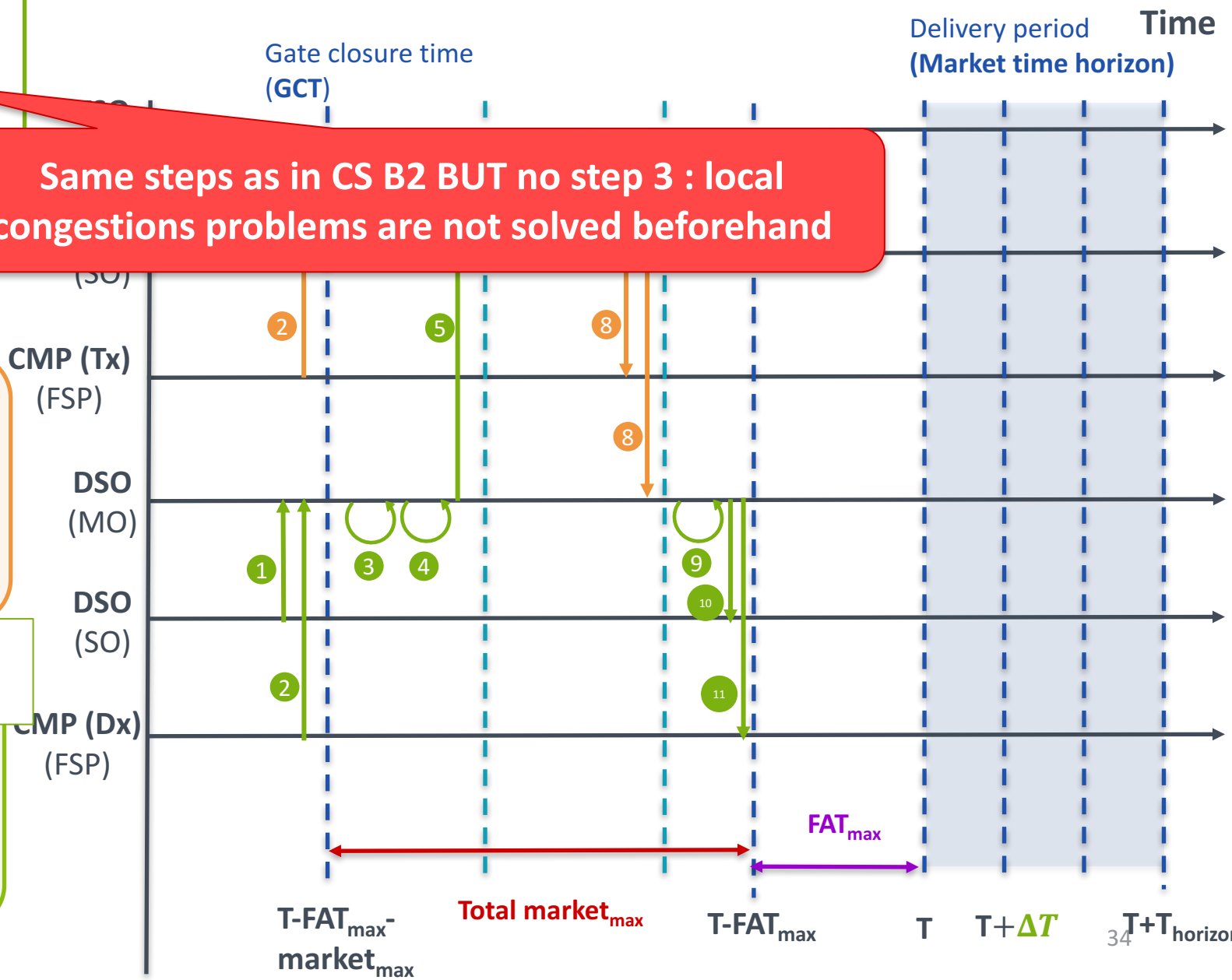
TSO-DSO CS-dependent
Timing Dimension

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}**

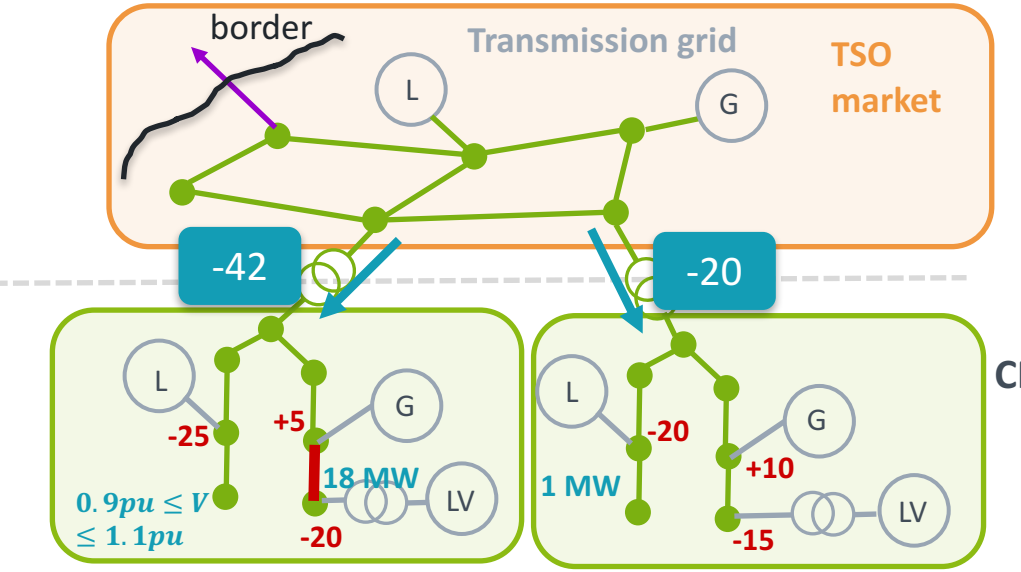




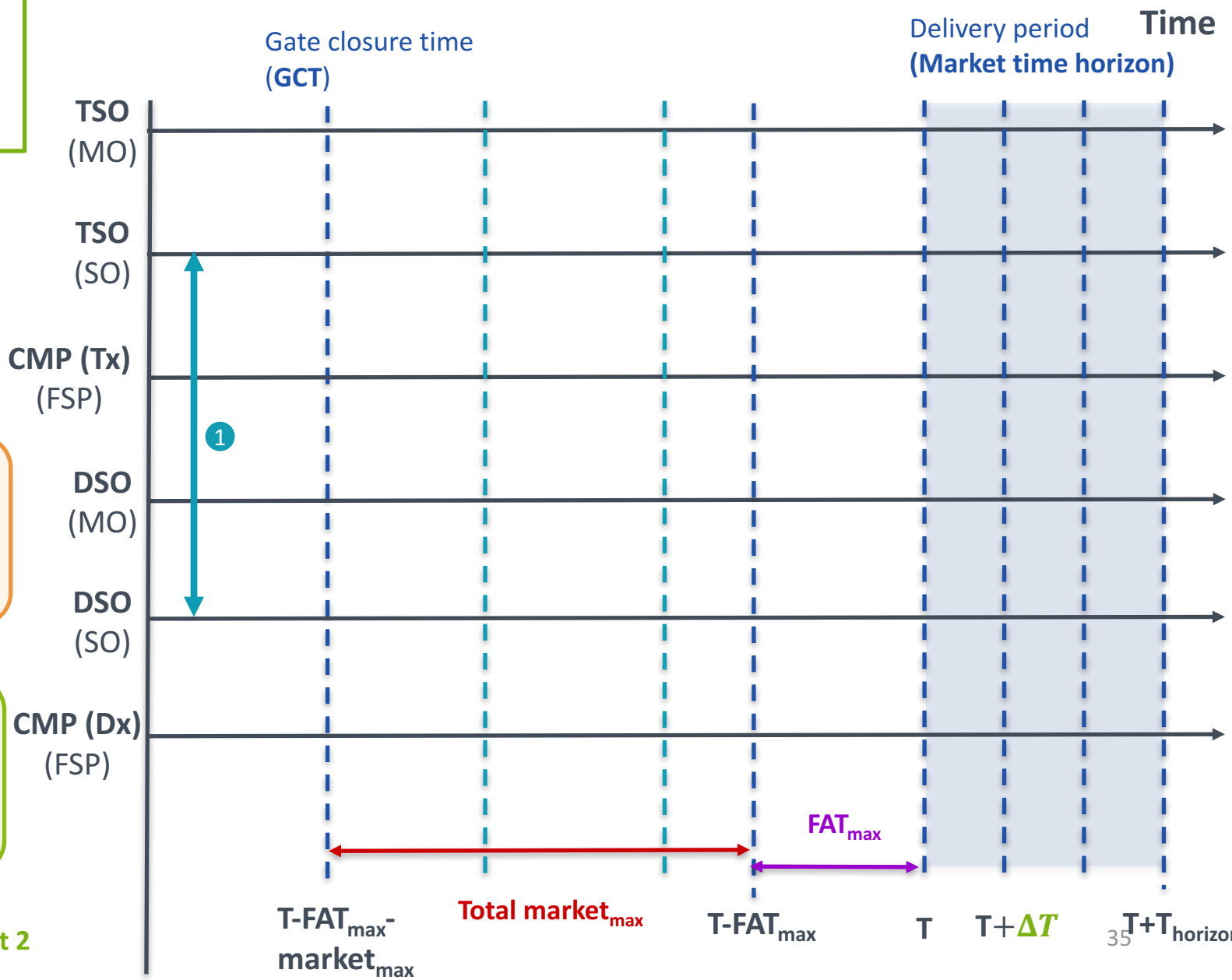
TSO-DSO CS-dependent
Timing Dimension

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)



Forecasted **imbalance** = **-15MW**

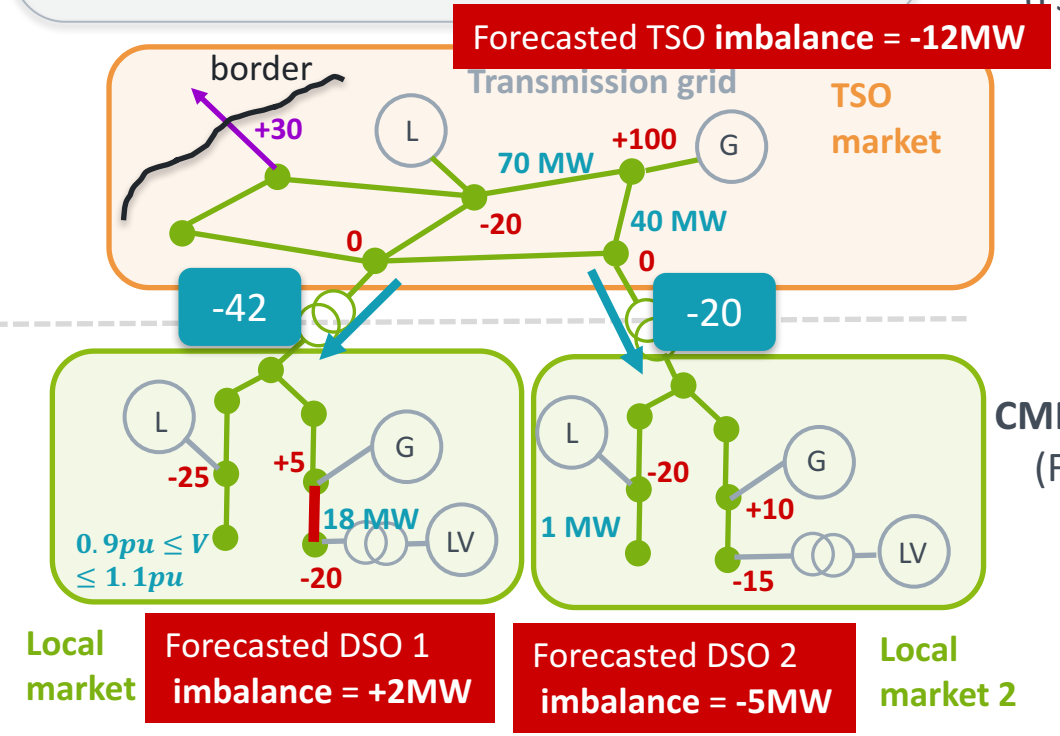


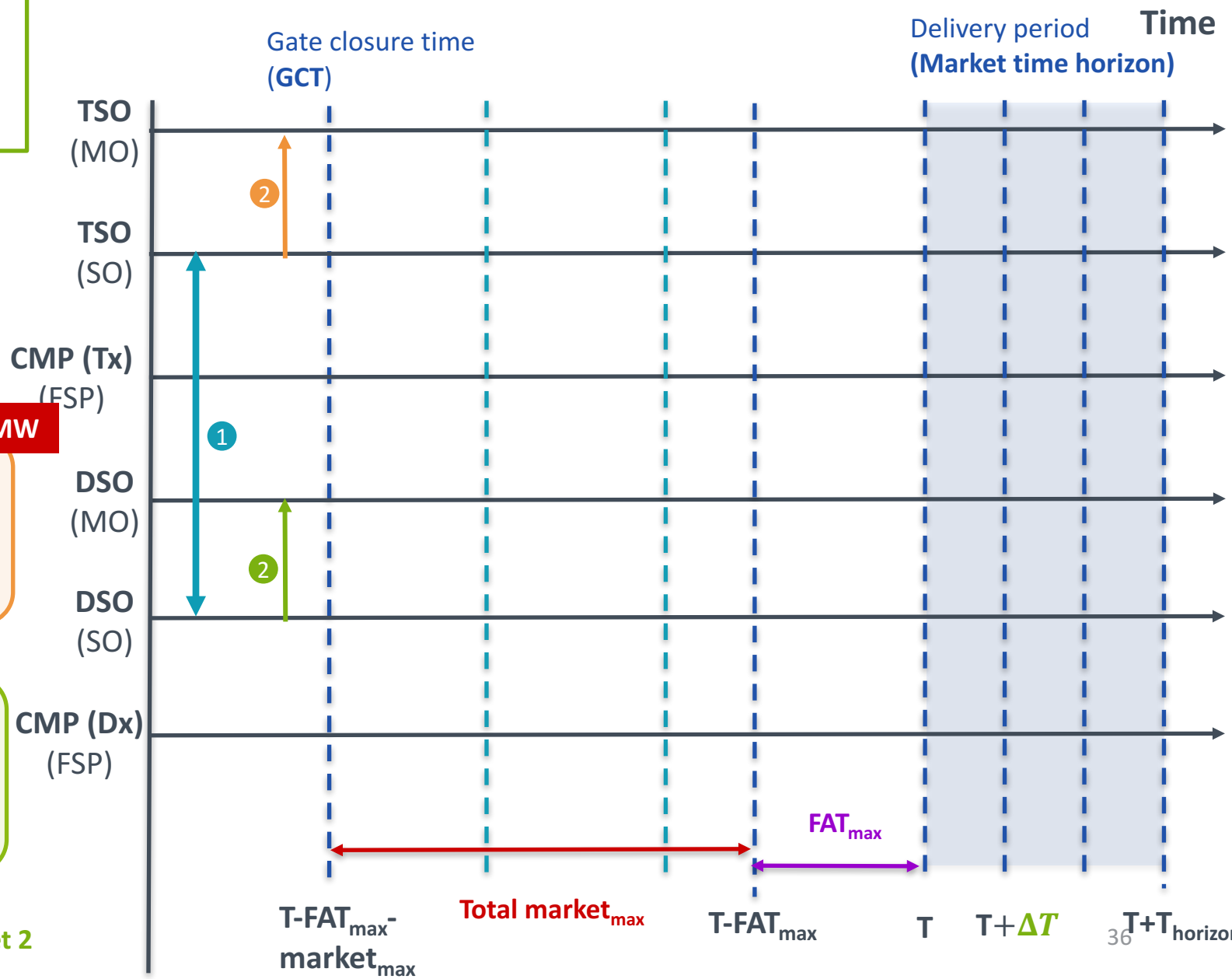
TSO-DSO CS-dependent
Timing Dimension

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**

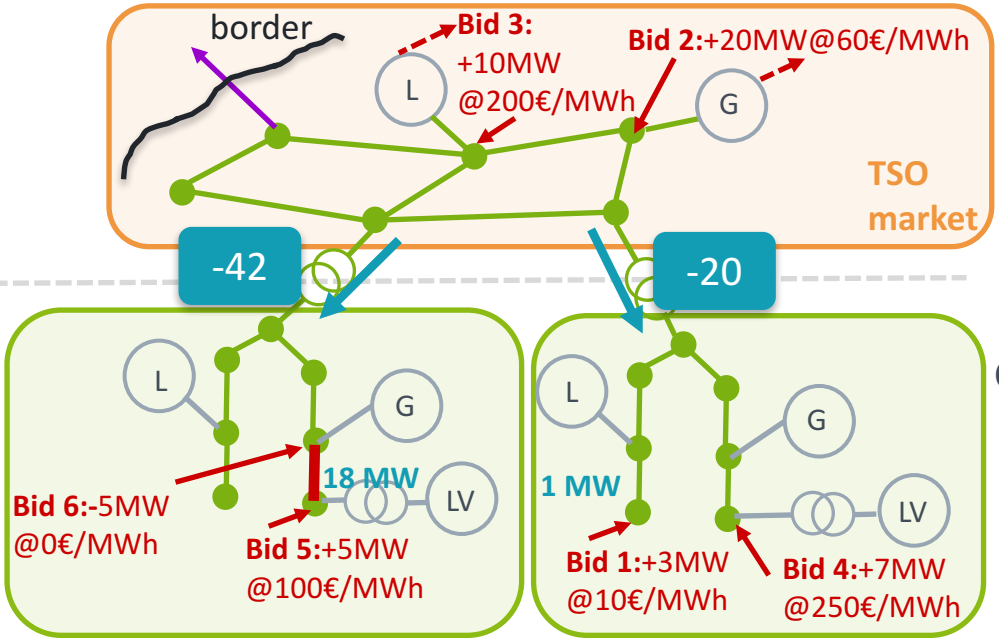


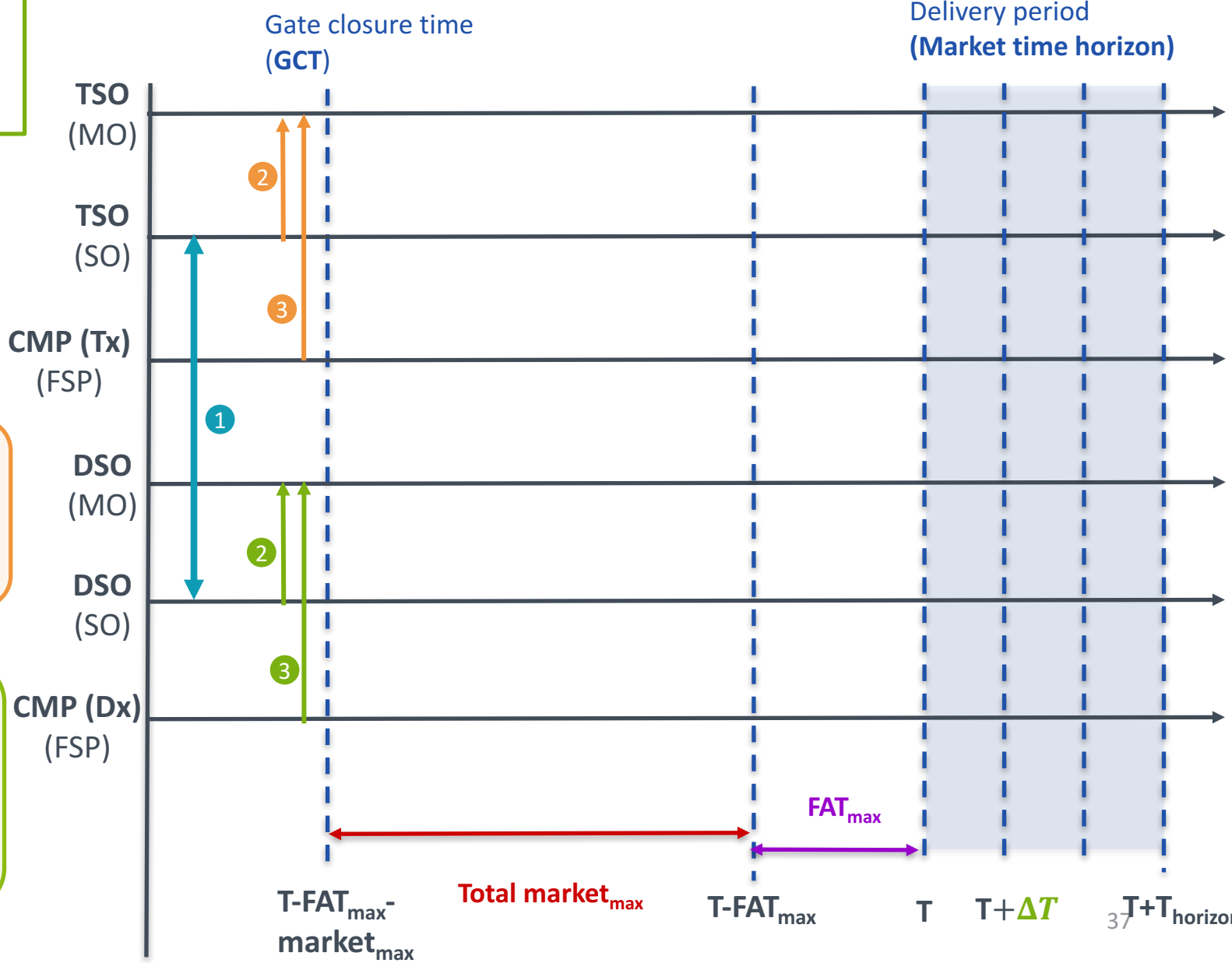


TSO-DSO CS-dependent
Timing Dimension

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**

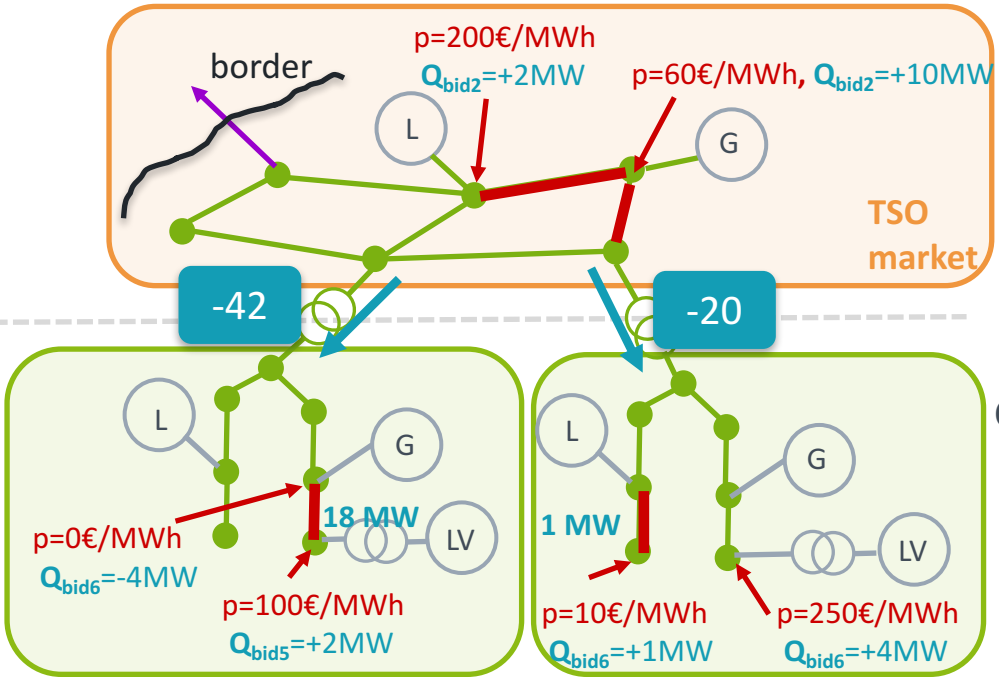


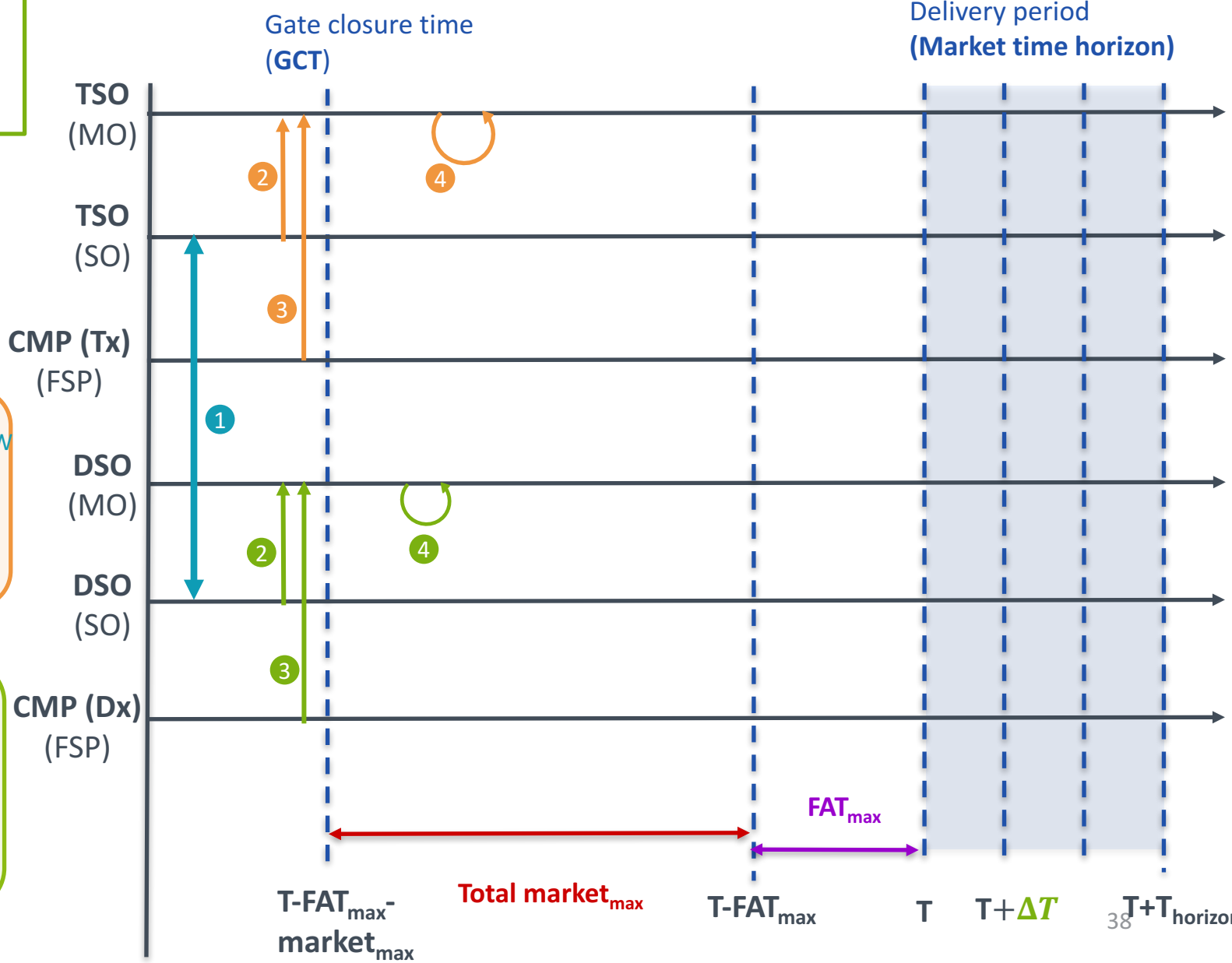


TSO-DSO CS-dependent
Timing Dimension

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**.

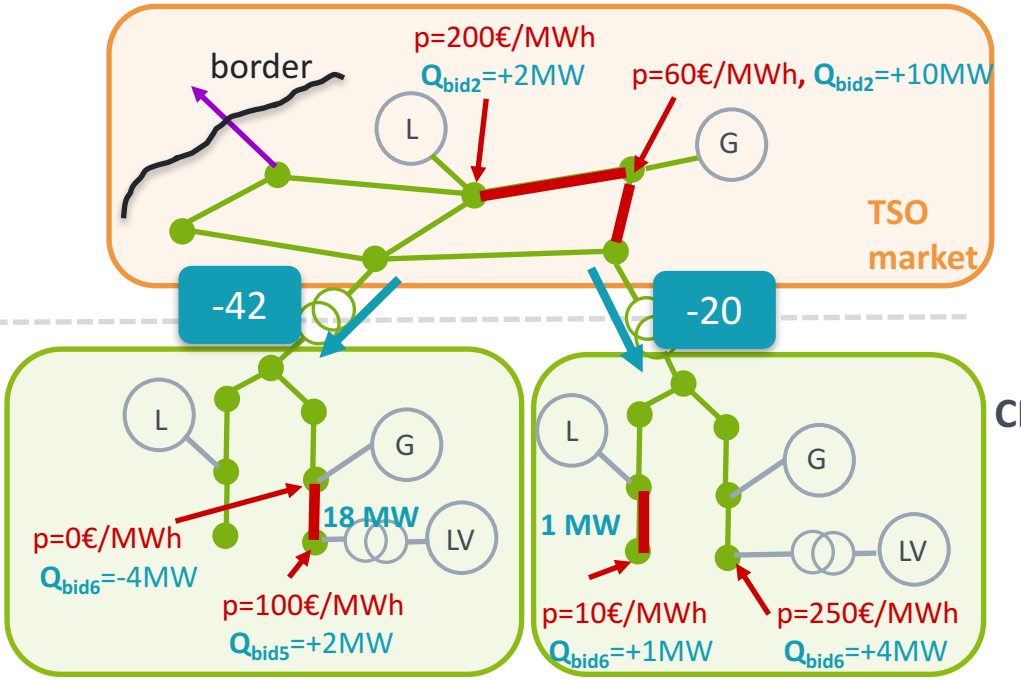


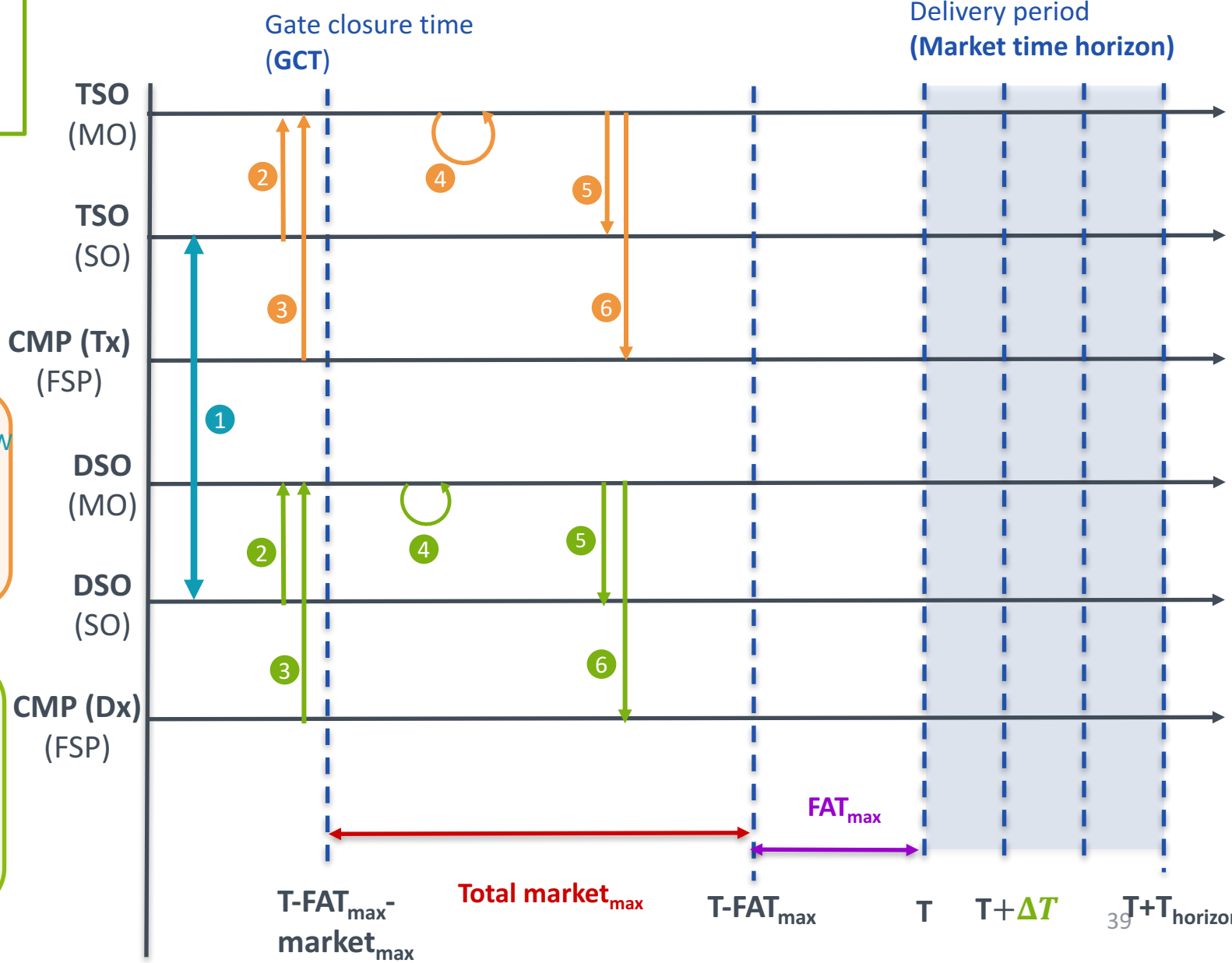


TSO-DSO CS-dependent
Timing Dimension

CS C: Shared balancing responsibility

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





Outline

- SmartNet AS **market scope** in the simulation platform

- **Market design ingredients**
  - Key **generic** ingredients
  - **TSO-DSO** coordination scheme **specifics**

- **Challenges**

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

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Thank You

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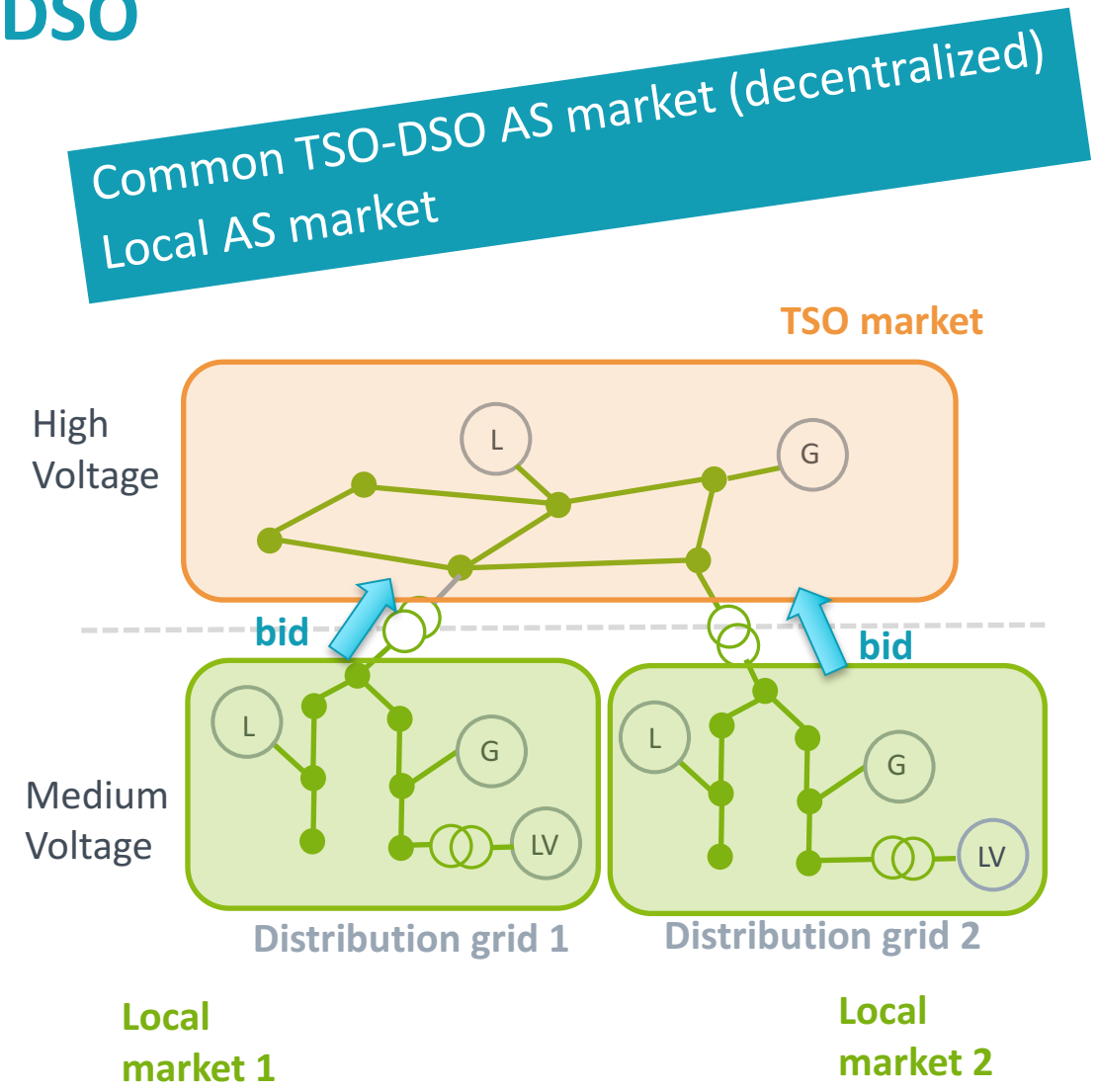
A bit more on “Smart” aggregation by the DSO

- (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