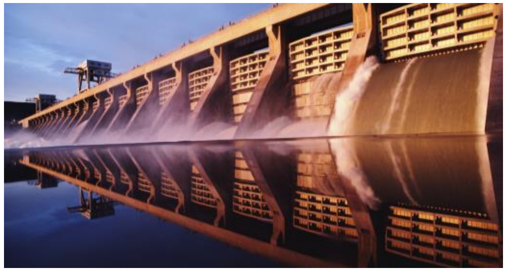  

Workshop Developments in Balance Management in Europe

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4th Annual European Electricity Ancillary Services & Balancing Forum, Berlin, 11-13 september 2013

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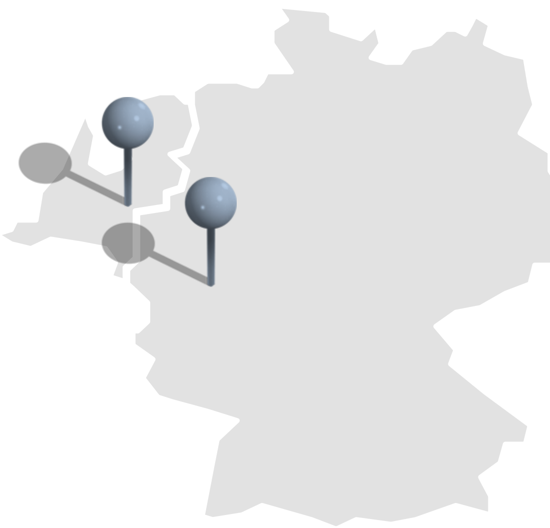
Who is E-Bridge

- E-Bridge is an international consulting firm specialized in the electricity and gas supply industries. E-Bridge bridges the gap between high-level corporate strategy and technical implementation
- Extensive experience in market restructuring and regulation
  - From CWE to the Nordic region, Germany, Austria, Poland, South-Korea, Belarus, Bulgaria, Turkey and Cyprus
- Linked with an extensive operational experience in the energy industry
- Strong competence in adapting operating and planning processes to balance "quality of supply", "costs" and "risks“
- E-Bridge operates from two offices
  - Germany, Bonn, with 15 consultants and associate consultants
  - The Netherlands, Oosterbeek (Arnhem area), with 3 consultants



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Part I: System Balancing, the basics

- Definition
- Power Balance and Frequency
- Frequency Containment
- Frequency Restoration
- Reserve Replacement
- System Balancing Process

System Balancing

In the widest context:

- All actions and processes (starting from assessing, planning, procuring all the way to real-time operations) through which TSOs ensure that the total electricity withdrawals from the grid are equaled by the total injections into the grid in a continuous way, in order to maintain the system frequency within a predefined stability range

(Source: Mott McDonald/Sweco - 2013: Impact Assessment on European Electricity Balancing Market)

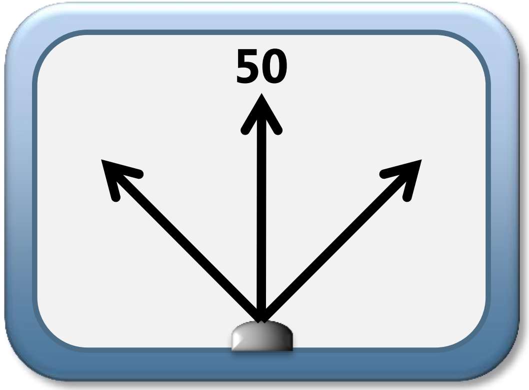
In the technical context:

- Keeping the frequency in an interconnected AC network within technical quality standards:
  - Target value, max. variation, continuity, etc.

More popular:

- Maintaining the balance between total feed-ins and take outs of electrical energy into and out of the entire interconnected AC network
- Keeping the balance between active power supply and demand

Frequency



Power balance and frequency

- Frequency is a uniform parameter within an interconnected AC network: at any point in a synchronized AC network, the same frequency is observed
- Within the interconnected AC network, there is a more or less constant relationship between the net active power balance of feed-ins and take-outs and the frequency, depending on the inertia of the system:
  - If there is more instantaneous take-out than feed-in, the frequency drops
  - If there is more instantaneous feed-in then take-out, the frequency rises
- Without adequate control, the frequency would keep rising/dropping as long as there is no compensation for the power imbalance
- What happens if the load in a synchronous network suddenly increases?

The effect of a demand increase explained

- Compare the synchronous network with a bicycle run by a rider paddling at a constant speed
- Consider that a passenger suddenly jumps at the back of the bicycle
- What would happen if the rider would not increase his effort to run the bicycle?
  - The bicycle would gradually come to a halt
- What would be required to stop the bicycle from coming to a halt?
  - The rider would need to increase his effort, let's call this a PRIMARY REACTION, directed at not coming to a halt
- What would be required to regain the original speed of the bicycle?
  - The rider would need to increase his effort even further, let's call this a SECONDARY REACTION, directed at regaining speed
- How does this work in the AC interconnected network?

How does this work in a synchronous system?

- Let us consider a simple system with one generator supplying a variable load
- When we neglect losses we have the following power balance equation:

$$P_m = P_e + P_a$$

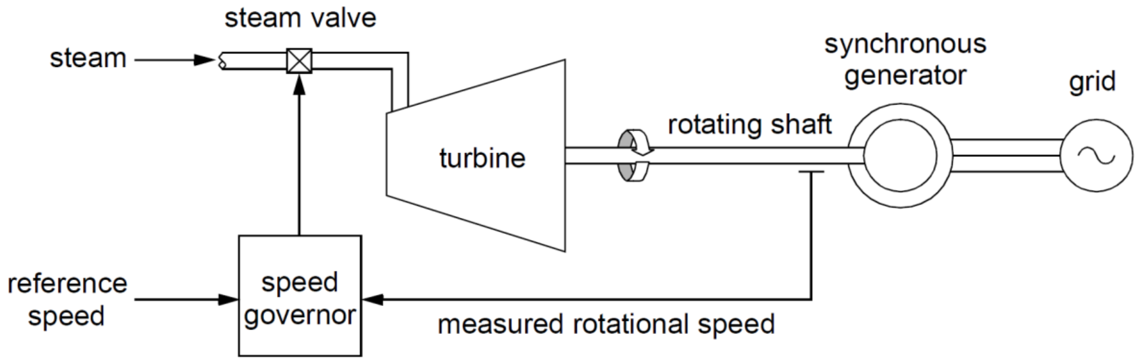
- Where
  - P_m is the mechanical power supplied to the generator axis by the prime mover
  - P_e is the eletrical active power output of the generator
  - P_a is the power accelarating or slowing down the generator

- Starting with a balanced situation, i.e. Pm=Pe and Pa=0, what happens if the load suddenly increases ($P_e \uparrow$)
- when no control actions are taken, Pm remains constant and in order to maintain the power balance, a decelarating power arises ($P_a \downarrow$) bringing the rotation of the generator down and the frequency of the electricl power output drops
- Without control action (increasing the mechanical power output P_m of the generator), the frequency keeps on declining

(see: "Electrical Power System Essentials", Schavemaker en van der Sluijs, Wiley. 2008, ISBN 978-0470-51027-8)

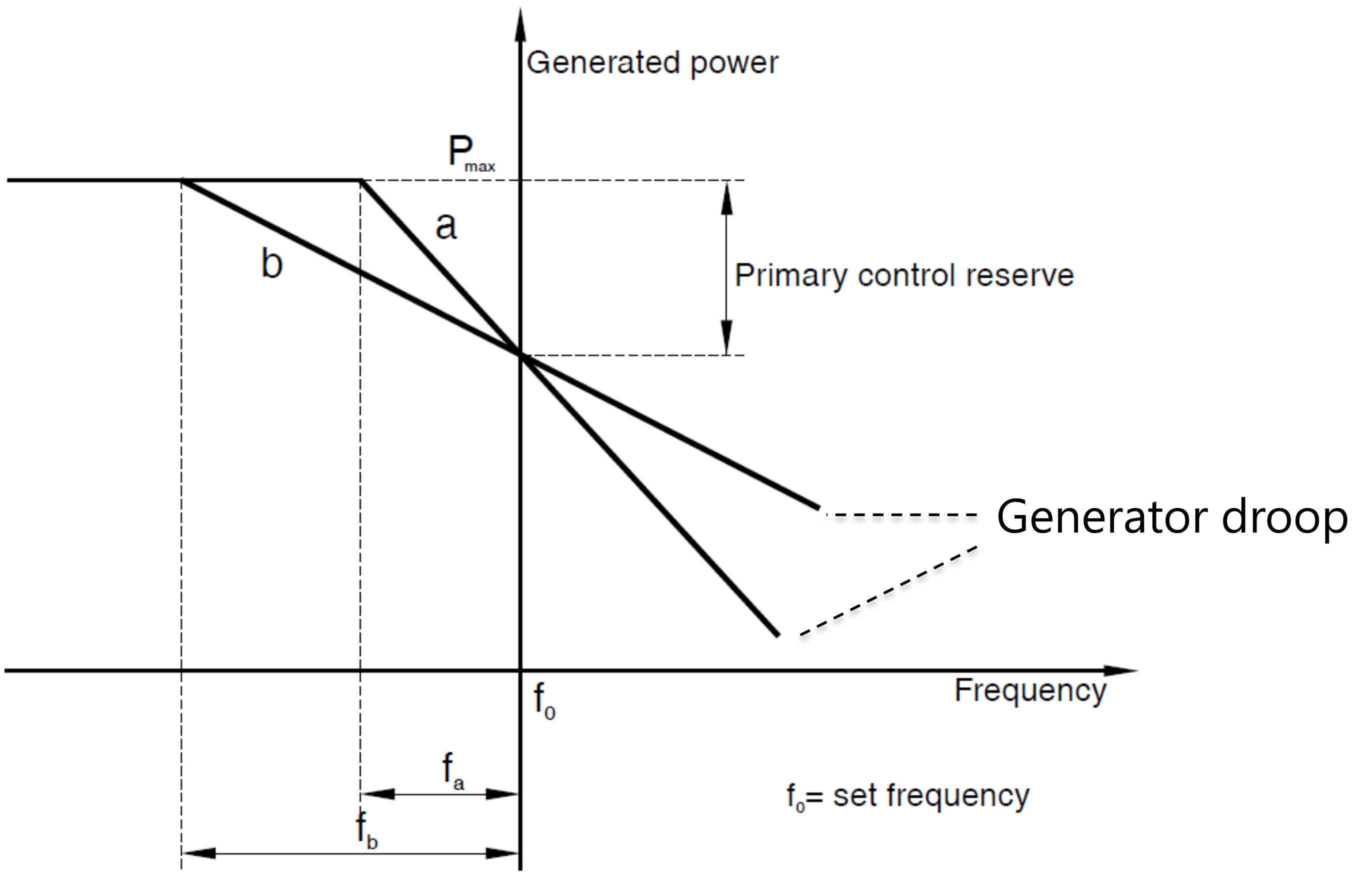
Primary control

- As wih the biker,the generator must increase the mechanical power supplied to the prime mover in order to restore the active power balance
- This is done through the speed governor control system on a generator



(source: "Electrical Power System Essentials", Schavemaker en van der Sluijs, Wiley. 2008, ISBN 978-0470-51027-8)

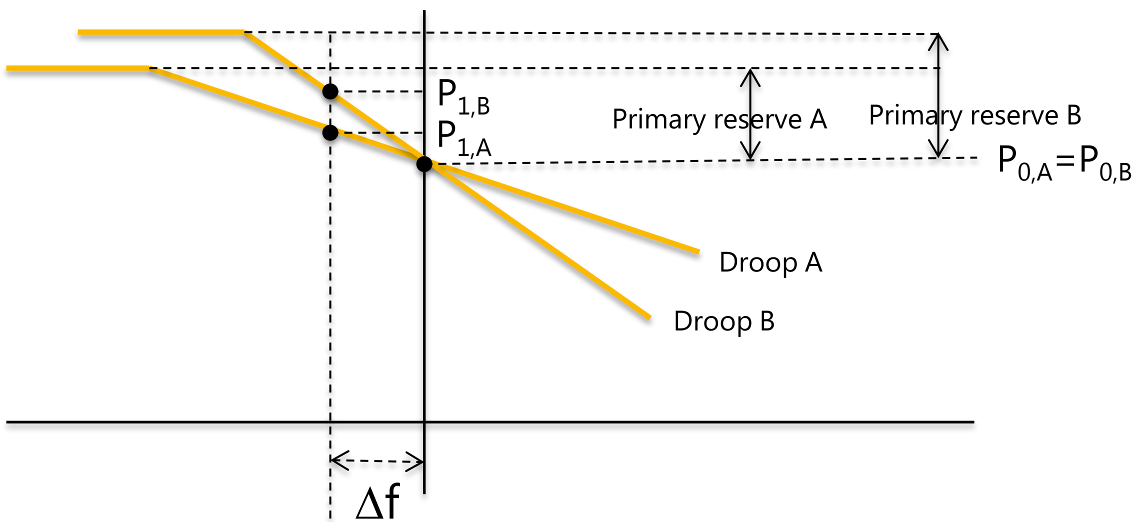
Primary control:



(Source: ENTSO-E, LFC&R Code, Appendix 1)

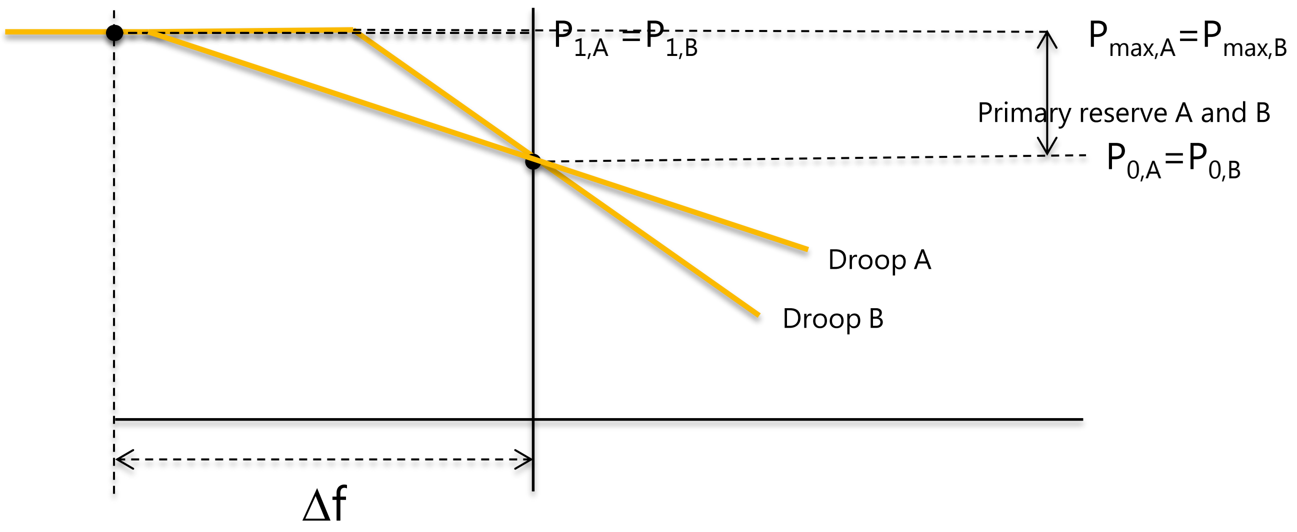
Primary control

- The droop settings, the generator capacity together with the primary reserve and the size of the frequency disturbance determine the contribution of each generator



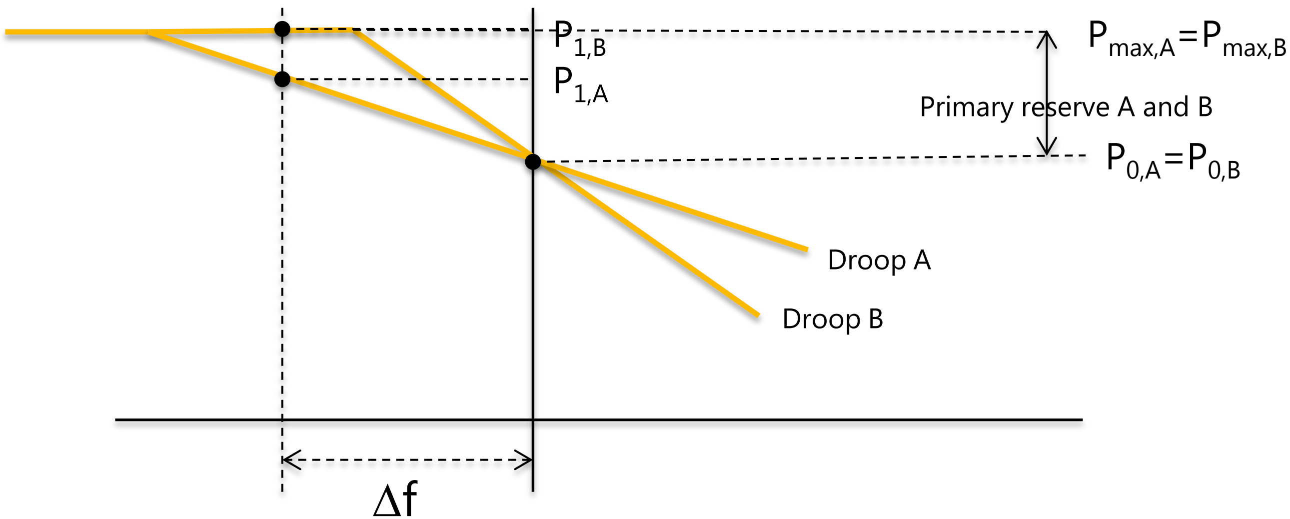
Primary control

- When the generators carry the same primary reserve, their contribution is the same if the frequency deviation is large enough



Primary control

- When the generators carry the same primary reserve, their contribution is not the same with smaller frequency deviations



Network Power Frequency Characteristic

- The relation between the scheduled and actual frequency on the one side and the amount of generation required to correct the power imbalance in the system is called the network power frequency characteristic:

$$\lambda = -\frac{\Delta P}{\Delta f} = -\frac{(P-P_0)}{(f-f_0)}$$

λ = the network power frequency characteristic (MW/Hz)

ΔP = the amount of generation required to correct the power imbalance (MW)

Δf = the difference between scheduled and actual system frequency (Hz)

- All generators in the synchronous network contribute to ΔP according to their droop characteristic:

$$\Delta P = \sum_i \Delta P_{gi} = \sum_i -\frac{1}{R_{gi}} \cdot \frac{P_{gi,r}}{f_r} \cdot \Delta f$$

Contribution of load to power balance

- Motors cause the system load to be slightly frequency dependent
- For this reason a self-regulating effect of the load is added to the network power frequency characteristic:

$$\lambda = -\frac{\Delta P}{\Delta f} = \sum_i \frac{1}{R_{gi}} \cdot \frac{P_{gi,r}}{f_r} + \frac{\mu}{100} \cdot P$$

- Where P is the system load after the frequency deviation has ocurred and μ is the load self-regulation effect in %

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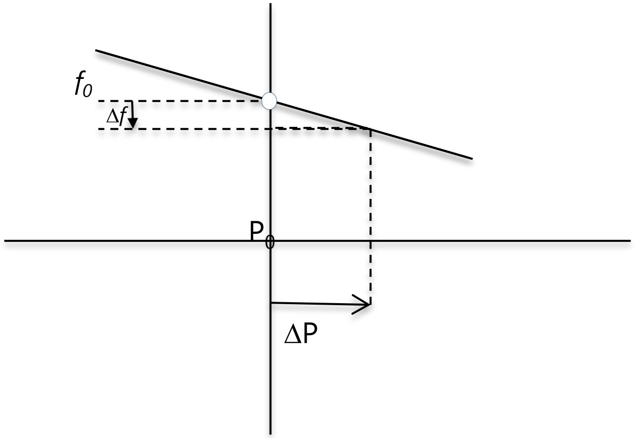
Load Frequency Control

- When a disturbance of the power balance occurs, the resulting frequency change is contained by the primary control on the synchronous generators in the system and by the self-regulating effect of the demand
- However, the primary control contains the frequency at a different level than the target frequency
- To restore the frequency, more energy needs to be added to the rotator
- The required control action, directed at restoring the frequency, is also called secondary control
- Different to the primary control action, which is common for all rotating generators (even wind and PV generators can participate today), the secondary control action can be provided from dedicated generators
- After the secondary control action by the generator, the generator is delivering the same power as after the primary control, but at a higher energy input level
- Generators that do not participate in the frequency restoration process / secondary control action will return to the orginal power level, after the frequency has been restored



Load Frequency Control: who should react?

- Power Balancing in a synchronous network is a distributed task among the TSOs
- Each area under control by a TSO is called a control area and each control area has it's own network power frequency characteristic λ_i
- Whereas the frequency containment process (primary control) is a shared common process, between the TSOs of an interconnected synchronized network it has been historically decided that the secondary control reaction should only be provided from the TSO control area which caused the power imbalance
- But how to determine which control area has caused the power imbalance?
- The way to do this is by monitoring the control area's imbalance:

$$P_{a,i} - P_{s,i} \, ,$$

  where Pa,i is the actual and Ps,i the scheduled exchange of the control area
- Of course, this exchange deviation needs to be corrected for the expected primary control reaction of the control area:

$$-\lambda_i . \Delta f$$

- If the actual exchange deviation equals the primary reaction, the power imbalance is caused outside the control area

Area Control Error

- The difference between the exchange deviation from schedule and the primary control reaction is called the AREA CONTROL ERROR (ACE)

$$ACE_i = (P_{a,i} - P_{s,i}) + \lambda_i \,.\, \Delta f$$

- Note that the sum of all ACEs in a synchronous system yields zero:

$$\Sigma_i\,(ACE_i) = \Sigma_i\,\{(P_{a,i} - P_{s,i}) + \lambda_i \,.\, \Delta f\} = \Sigma_i\,(P_{a,i} - P_{s,i}) + \Sigma_i\,(\lambda_i \,.\, \Delta f) =$$

$$\Delta P + \lambda . \Delta f = \Delta P + \lambda \,.\, -\Delta P/\lambda = 0$$

- So only the control area with a non-zero ACE has to activate a secondary control action

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The control area concept, an example

Excercize:

- The frequency in the network is 50 Hz, all control areas are in balance
- The network power frequency characteristic of UCTE is approx. 30000 MW/Hz
- A control area has a network power frequency characteristic of 3000 MW/Hz
- Suppose an outage of 300 MW occurs
- What will be the resulting frequency?
- What will be the deviation of exchange from the schedule for the control area?

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The control area concept, an example (2)

Answer

- Outage of 300 MW:

  $\Delta P = 300$ (the required increase of active power to correct the imbalance)

- Resulting frequency after primary control reaction:

  50 - 300 / 30000 = 49,99 Hz

- The required contribution of the control area to the primary control reaction is:

  3000 . 0,01 = 30 MW

- The exchange deviation from schedule of the control area depends on where the outage occurred
  - If within the control area, the exchange deviation will be to import 300 MW more than scheduled, minus the primary control action contribution:

    300 - 30 = 270 MW

  - If outside the control area, the exchange will only deviate with the primary reaction:

    -30 MW

A synchronous system with three control areas

Power frequency characteristics

- Area A: 13000 MW/Hz
- Area B: 16000 MW/Hz
- Area C: 11000 MW/Hz

For the whole system the network power frequency characteristic is the sum of the individual characteristics: 40000 MW/Hz

With a loss of a 400 MW generator in area B, the frequency thus changes with

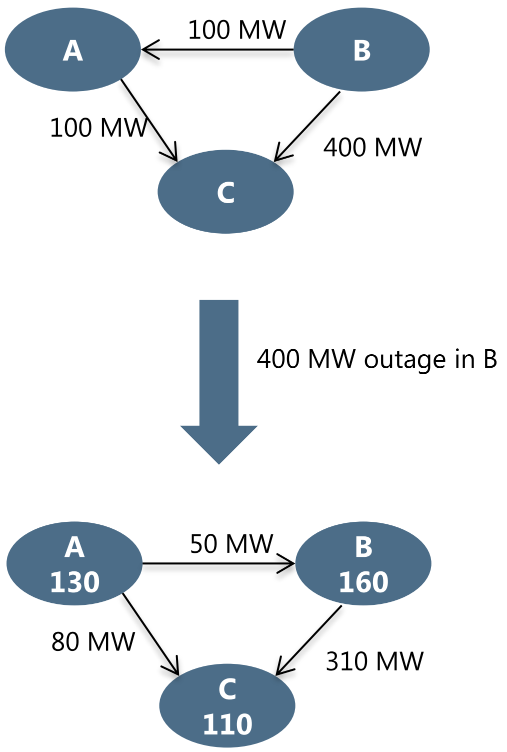
$$-400/40000 = -0{,}01 \text{ Hz}$$

The contribution of each control area to the primary control reaction is:

- Area A: ΔP_A = -13000 . -0,01 = 130 MW
- Area B: ΔP_B = -16000 . -0,01 = 160 MW
- Area C: ΔP_C = -11000 . -0,01 = 110 MW

And the area control error of each area becomes

- Area A: $(P_{A,a}-P_{A,s}) + -\lambda_A . \Delta f$ = (130 – 0) + 13000.-0,01 = 0 MW
- Area B: $(P_{B,a}-P_{B,s}) + -\lambda_B . \Delta f$ = (260 – 500) + 16000.-0,01 = -240 – 160 = -400 MW
- Area C: $(P_{C,a}-P_{C,s}) + -\lambda_C . \Delta f$ = (-390 – (-500)) + 11000.-0,01 = 0 MW



The system balancing process

Basically the system balancing process is build up from two control processes

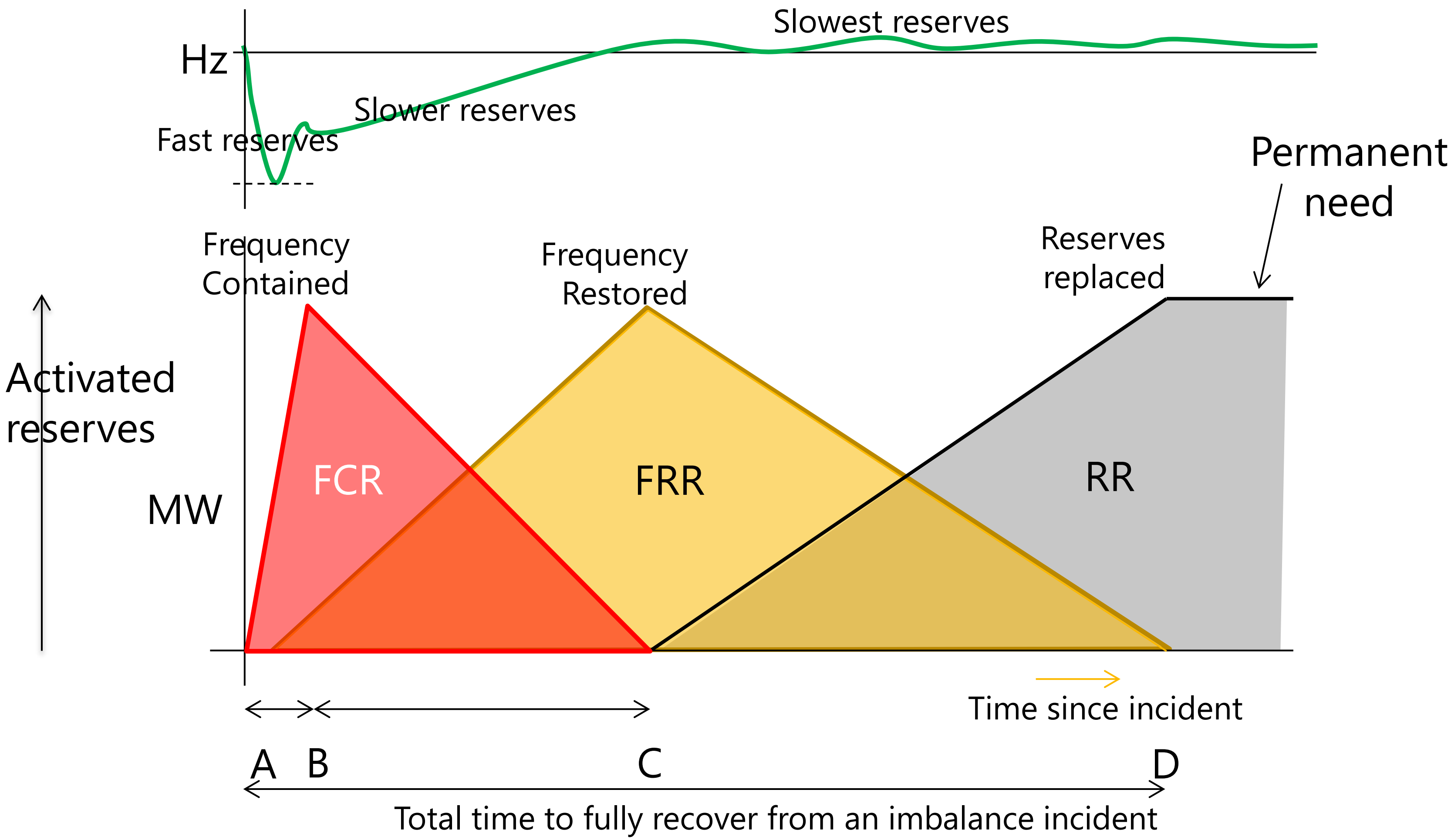
- A FREQUENCY CONTAINMENT PROCESS where all generators contribute according to the droop setting of their primary controller
  - The reserves for this process are called (ENTSO-E) FREQUENCY CONTAINMENT RESERVES (FCR)
- A FREQUENCY RESTORATION PROCESS which only reacts in the control area where the imbalance occurs
  - The reserves for this process are called (ENTSO-E) FREQUENCY RESTORATION RESERVES (FRR)

Now what happens to the reserves that were activated?

- The FCR activated for the primary reaction are freed up again by the secondary control reaction
- But the FRR activated by the secondary control action will remain to be used until they are replaced by instruction

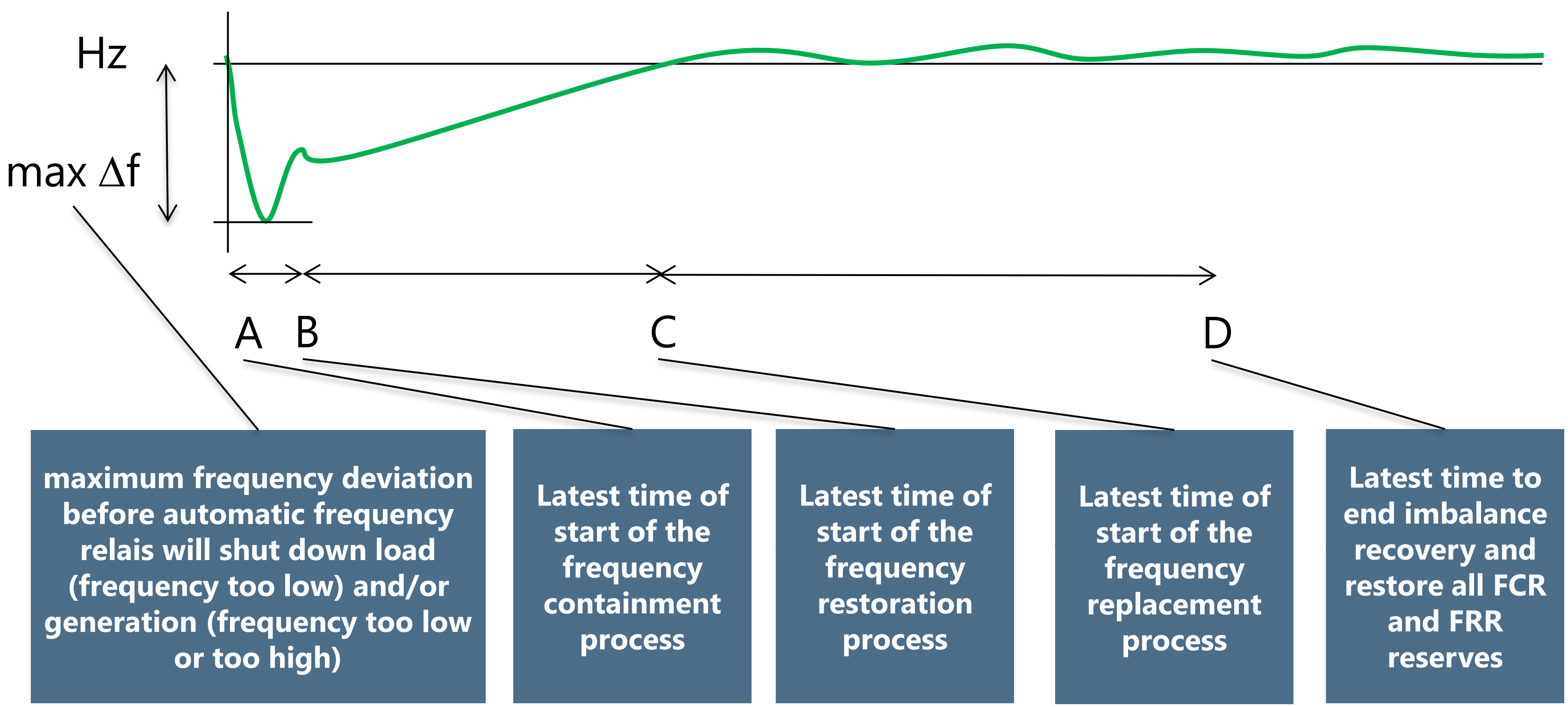
The replacement of the FRR is ususally a question of redistributing the power over running (and non-running) generators in an efficient way

Imbalance recovery process (summary)

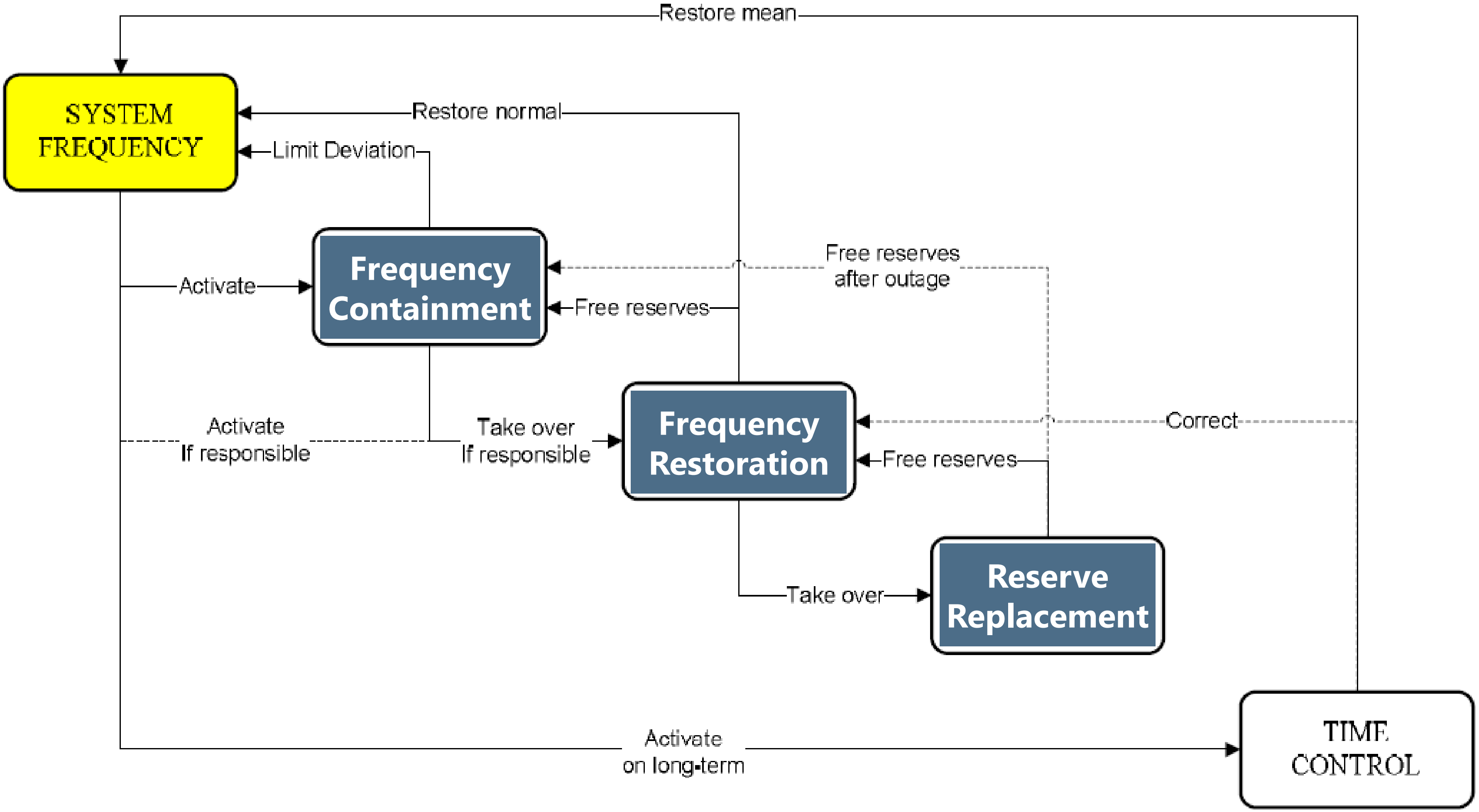


Dimensioning requirements

- The amount of operational reserves required for the TSO to maintain the system balance is partly an engineering question and partly a market design question
- The answer is determnined by the design parameters and the maximum volume of incidents to be covered during the TSO balancing responsibility window



The system balancing process overview



Source: UCTE

Balancing markets: the basics

- Definitions
- Types of markets
- TSO role in balancing
- Balance responsibility
- Settlement period
- Reserve procurement
- Pricing
- Performance indicators

Definitions

- System Balancing:

  All actions and processes (starting from assessing, planning, procuring all the way to real-time operations) through which TSOs ensure that the total electricity withdrawals from the grid are equalled by the total injections into the grid in a continuous way, in order to maintain the system frequecncy within a predefined stability range

- Balancing market

  The intirety of institutional, commercial and operational arrangements that establish market-based management of the function of System Balancing within the framework of a liberalised electricity market, consisting of three main parts:

  - Balance responsibility
  - Balance service provision
  - Imbalance settlement

Source: Mott McDonald/Sweco (2013): impact assessment on European Electricity Balancing Market

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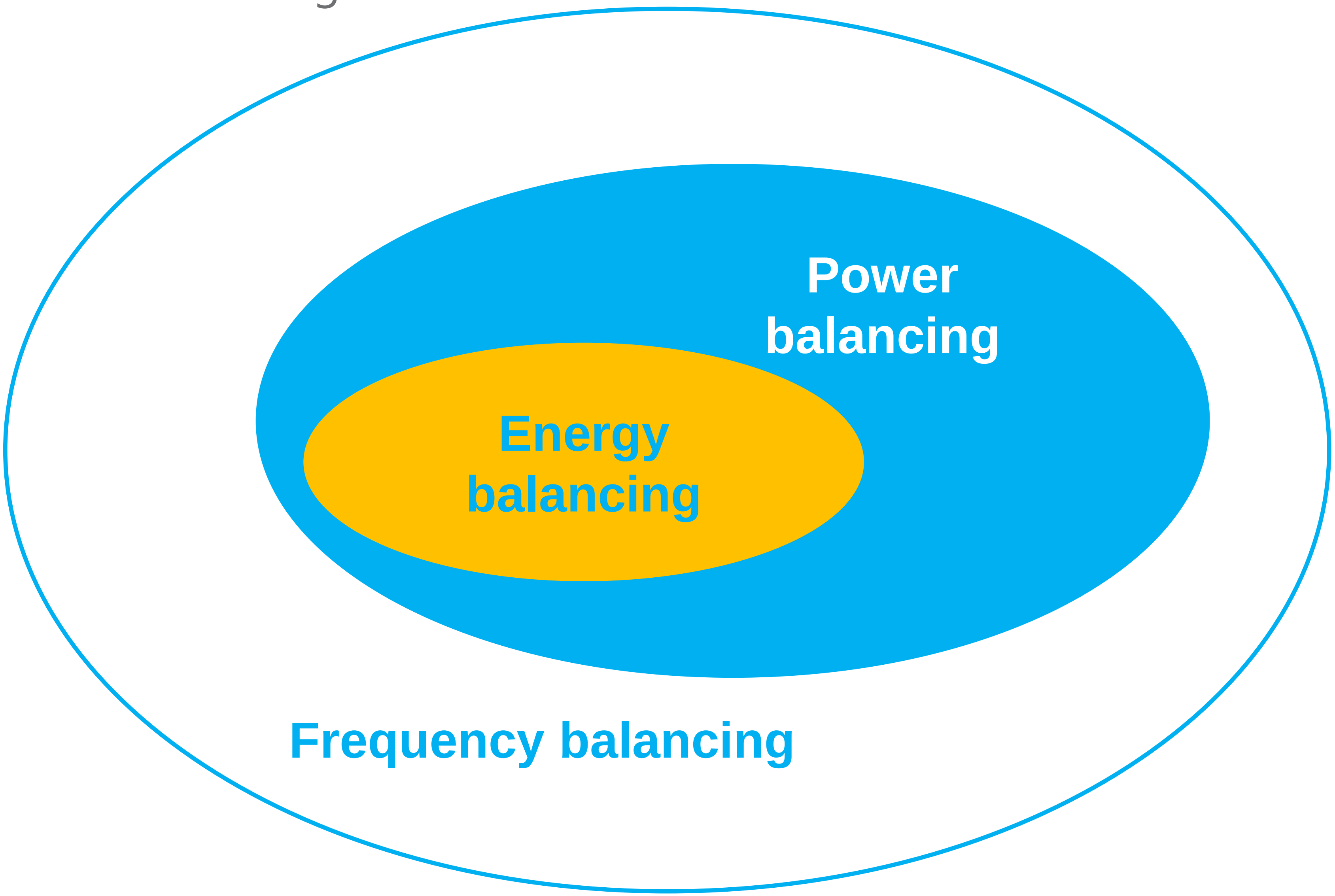
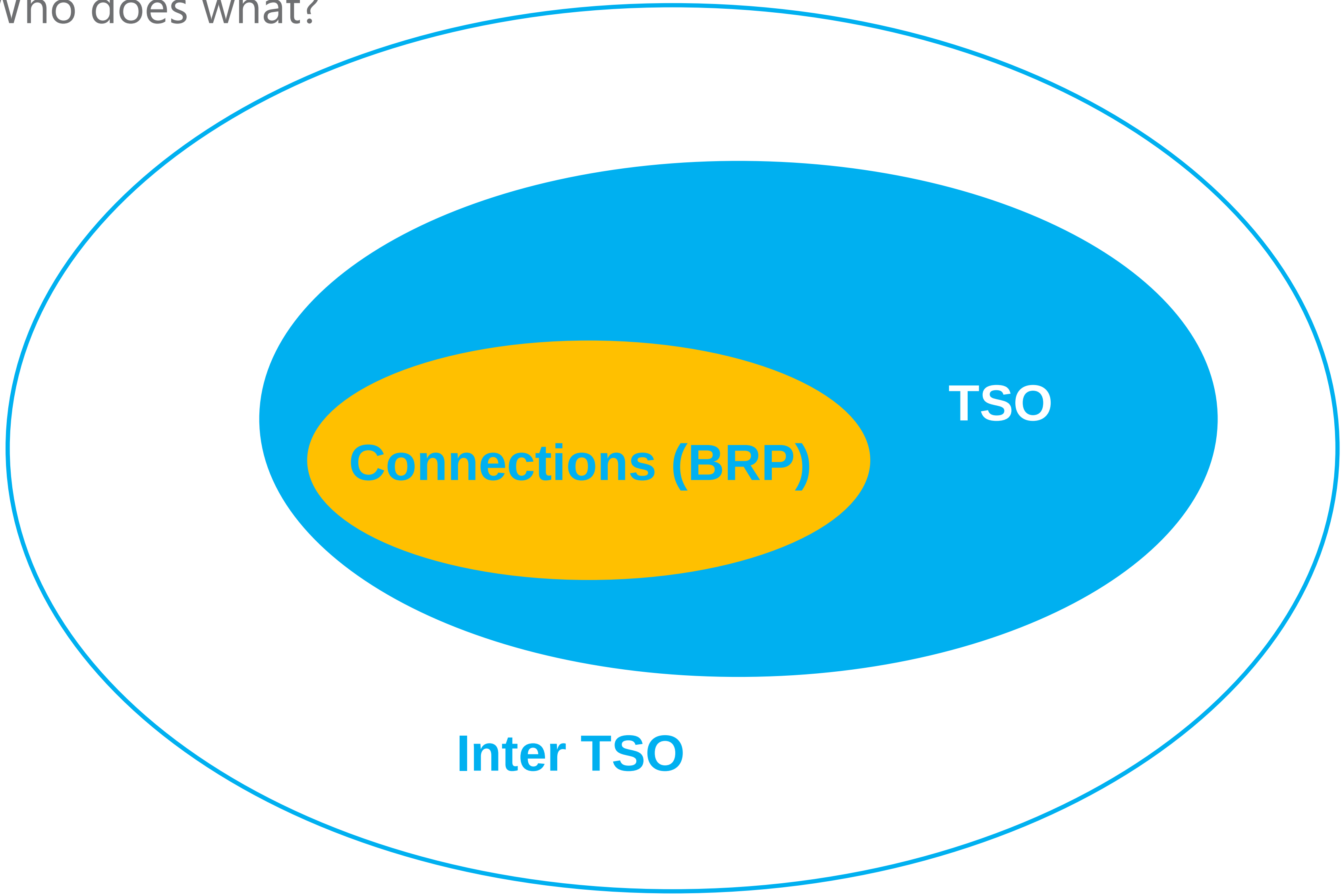
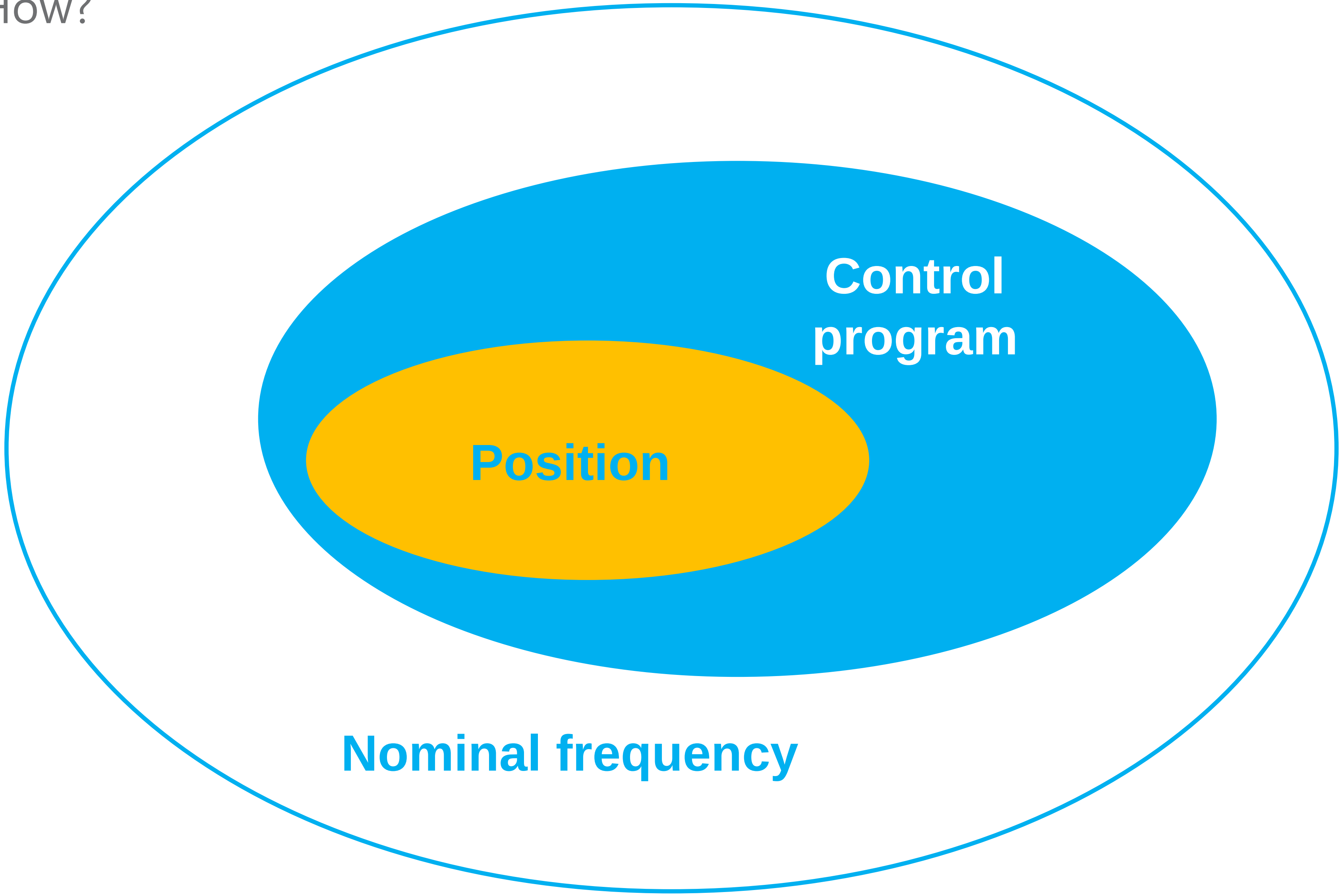
What is balancing?



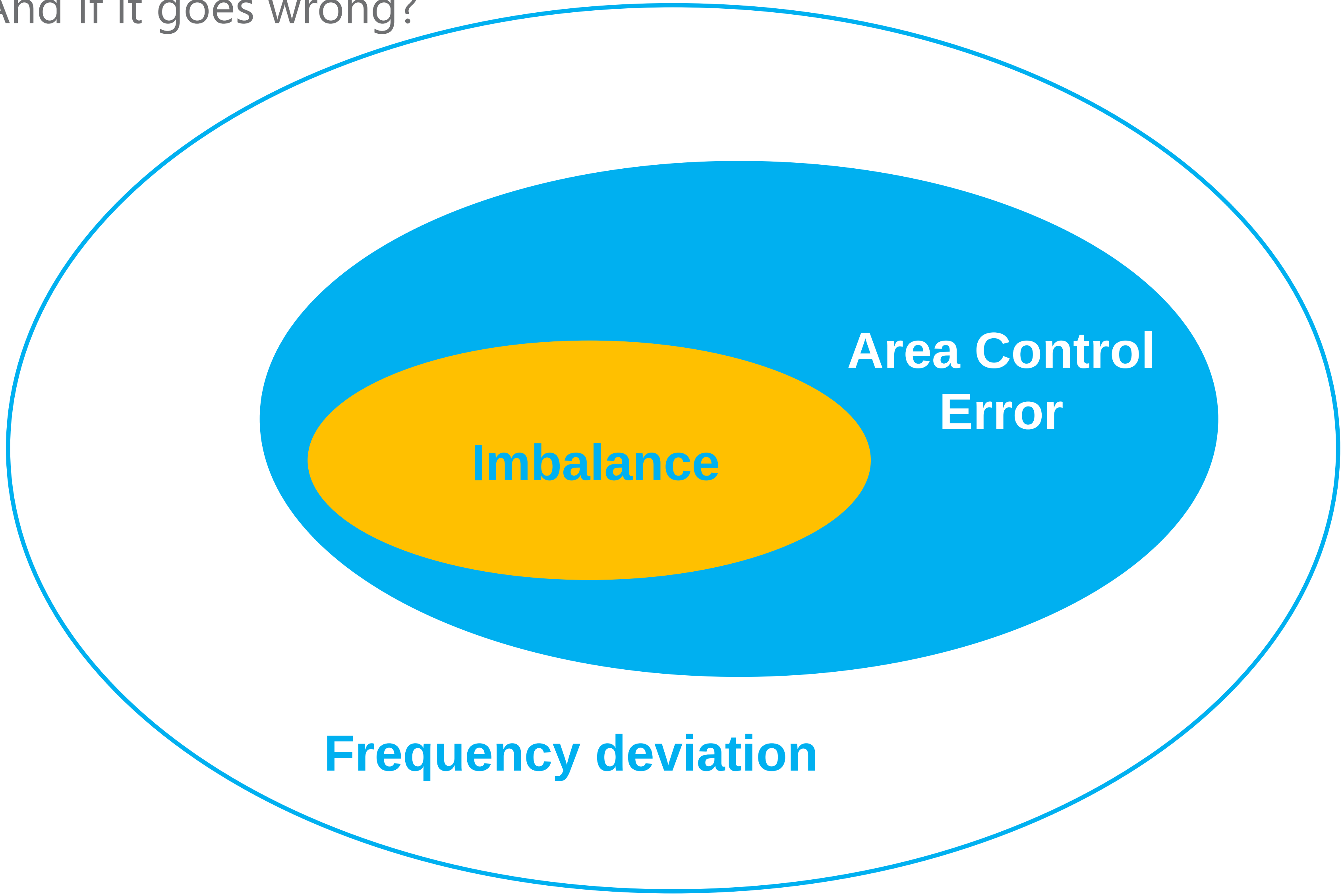
Who does what?



How?



And if it goes wrong?



Blackout

Types of markets

- Locational marginal pricing versus zonal pricing
- Central dispatch versus self-dispatch
- Gross pools, net pools and bilateral markets
- Energy markets and markets with capacity mechanisms

Locational marginal pricing and zonal pricing

- Locational marginal pricing
  - Considered more efficient in a network with lots of dynamic operational constraints
  - Requires central scheduling and dispatch
  - Efficiency issues with market innovation and demand side response
- Zonal pricing
  - Requires a stable network that acts as a copperplate within the zone
  - Allows self-scheduling and self-dispatch
  - Is supposed to provide maximum freedom to the market
  - Efficiency issues with network zones that are far from a copperplate

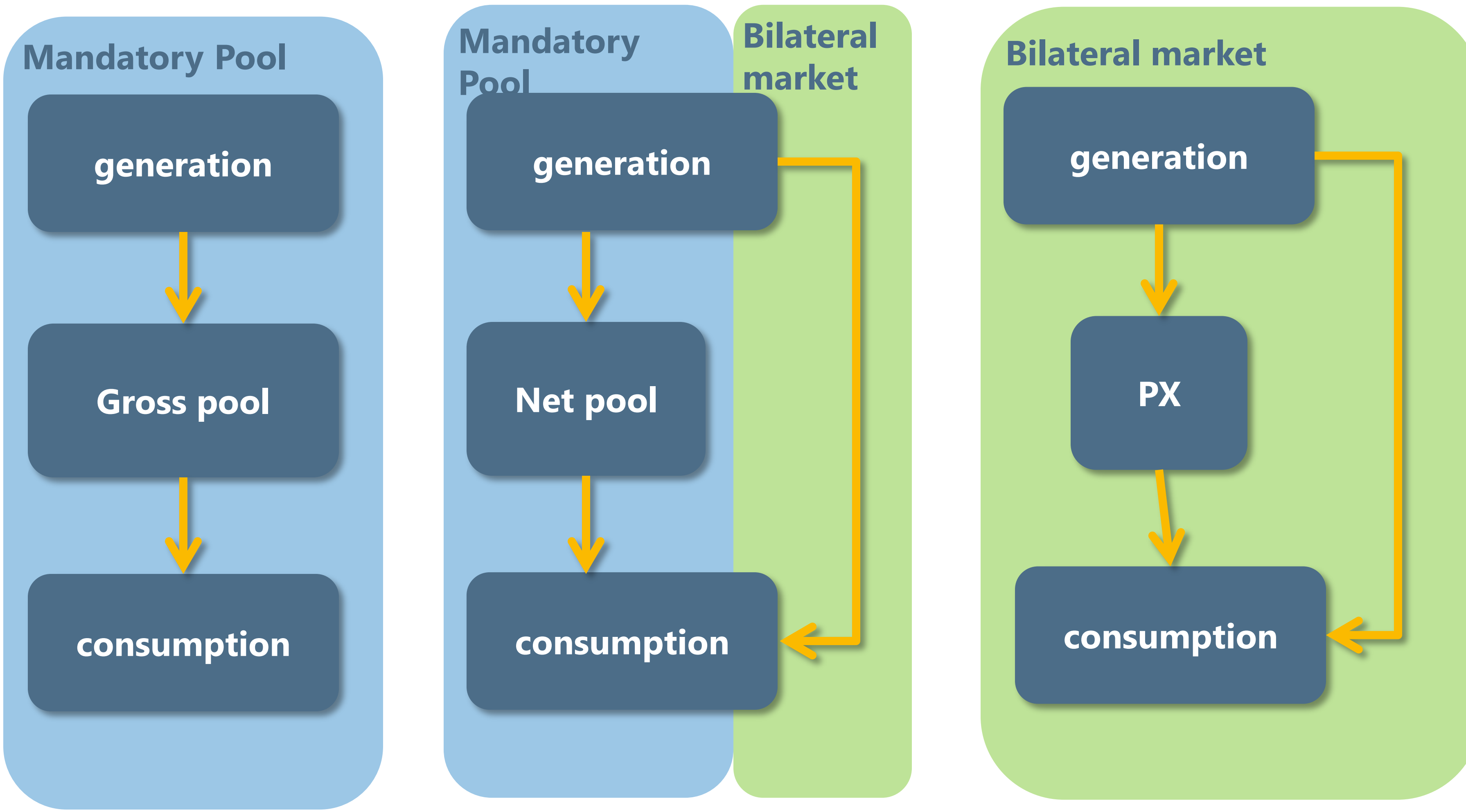
Locational marginal pricing and multi-stage settlement

- In a locational marginal pricing approach, two-stage settlement occurs through a central security constrained unit commitment and dispatch (day ahead, realtime)
  - The first stage is day ahead where supply and demand is settled against the locational marginal price calculated by a joint optimization on energy and ancillary services demand
  - The next stage is realtime where the same optimization is repeated on e.g. a 5 minute base. An average 1 hour LMP price is derived from the 5 minutes prices and charged for any imbalances (difference between measured and day ahead schedule)
  - There are always two locational marginal prices: one for energy, one for ancillary services

Central dispatch versus self-dispatch

- In a central dispatch system, all generation in the network is centrally scheduled and dispatched
  - with the objective to minimize the variable generation costs
  - the market has full freedom to invest, there is no transaction freedom and little freedom of dispatch
  - Usually the central dispatch operator is responsible to meet the demand
- Self-dispatch systems have the objective to provide the market maximum freedom of investment, transaction and dispatch
  - with the objective to let the market provide the most efficient electricity supply
  - usually (but not always) the market is responsible to meet the demand; where this is not the case, this creates issues with generation adequacy
- Hybrid systems combine self-scheduling (e.g. until market gate closure) with central reserve dispatch (after market gate closure)

Gross pool, net pool and bilateral markets



Gross pool, net pool, bilateral markets and balancing

- In gross pool arrangements, all market parties must participate and the balancing mechanism is usually integrated in the pool (realtime market price)
- In net pool arrangements the market is allowed to self-schedule, but what is not self-scheduled must participate in the pool and balancing is integrated in the pool (realtime market price)
- Full bilateral arrangements always have a separate balancing mechanism for procurement and activation of balancing reserves and energy

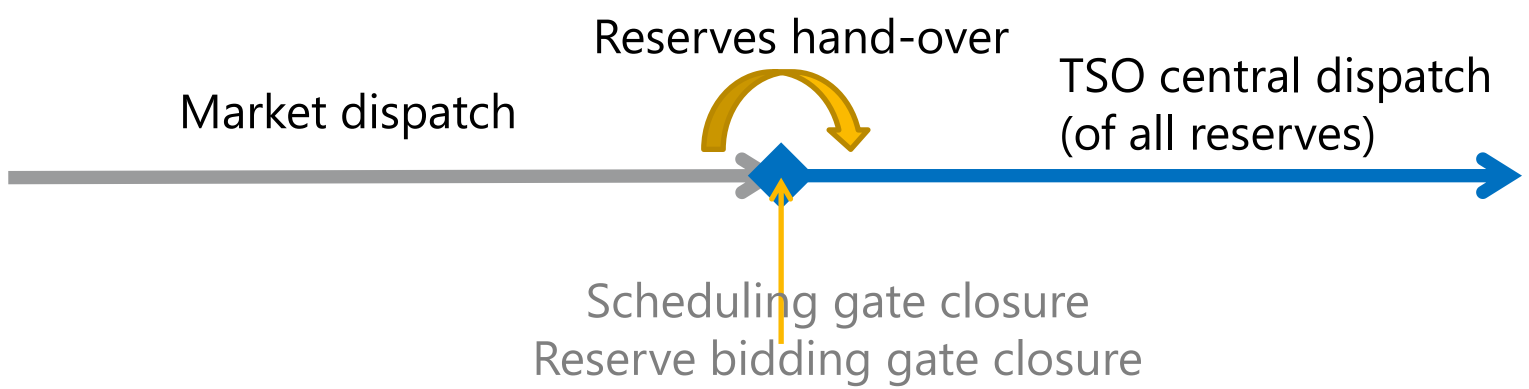
Energy only markets versus markets with capacity mechanisms

- In energy only markets, there is no pricing mechanism for generation capacity at the wholesale market level, capacity arrangements may exist in the balancing market (reserves capacity procurement) and through long term bilateral contracts
- All other markets have some kind of capacity mechanism
  - Capacity obligations
  - Capacity payments/credits
  - Capacity auctions
  - Capacity tenders
- A capacity mechanism is not needed provided there is no regulatory intervention on wholesale market prices
- In energy only markets, strategic reserves contracts may be considered as a safetynet for security of supply issues

TSO role in balancing: sequential versus parallel approach

- In a sequential approach, the market can self-schedule down to market gate closure and the TSO takes responsibility of energy and power balance
- In a parallel approach, the market can self-schedule down to realtime or even ex-post and the TSO only takes responsibility on the power balance
- In both systems the market is financially liable towards the TSO for imbalances between scheduled and realtime exchanges with the grid
- Hybrid systems occur

TSO role in balancing: sequential approach, central reserves dispatch



- In a sequential approach, the market can self-schedule down to market gate closure only and the TSO takes responsibility of energy and power balance after market gate closure

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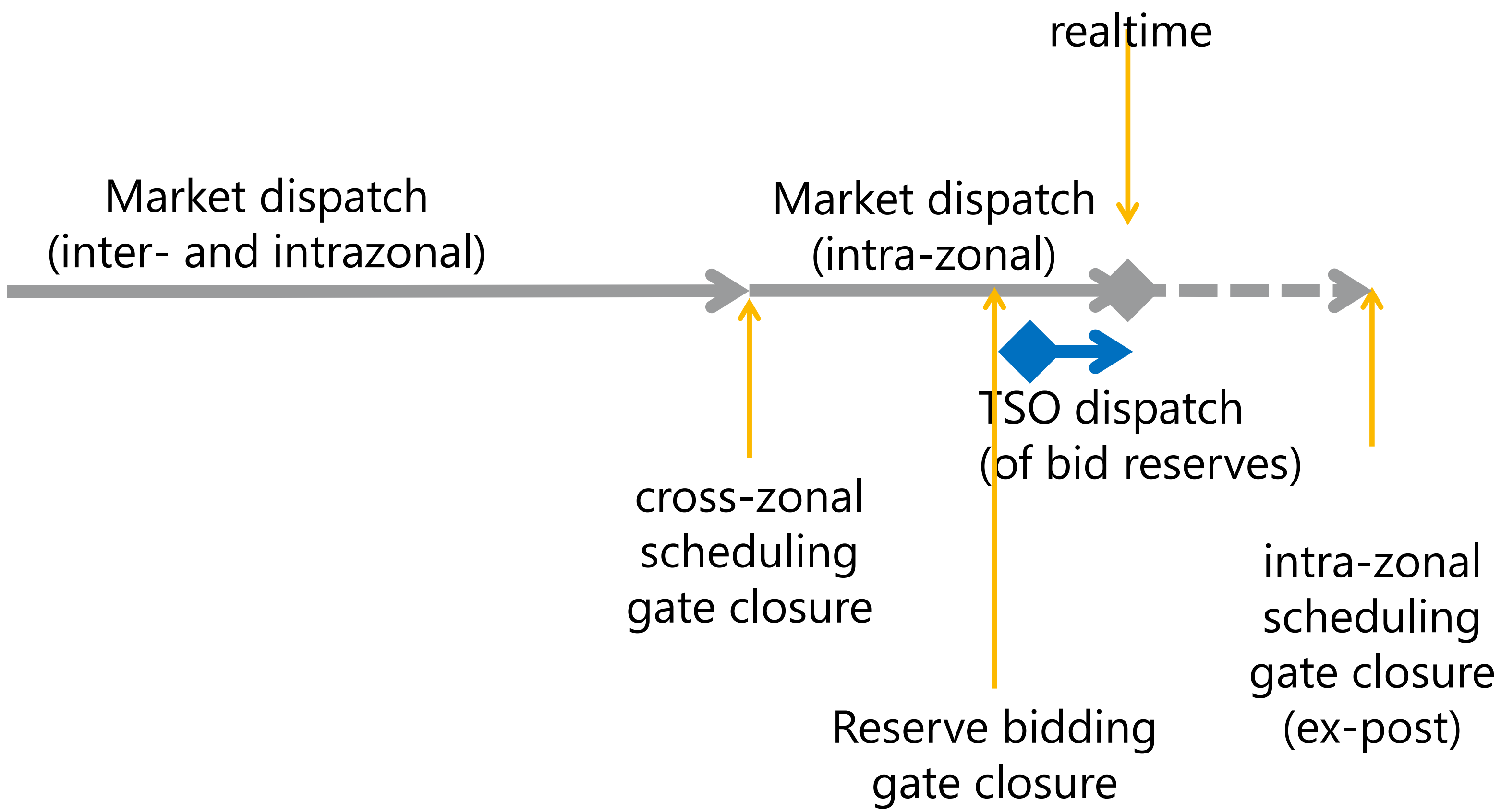
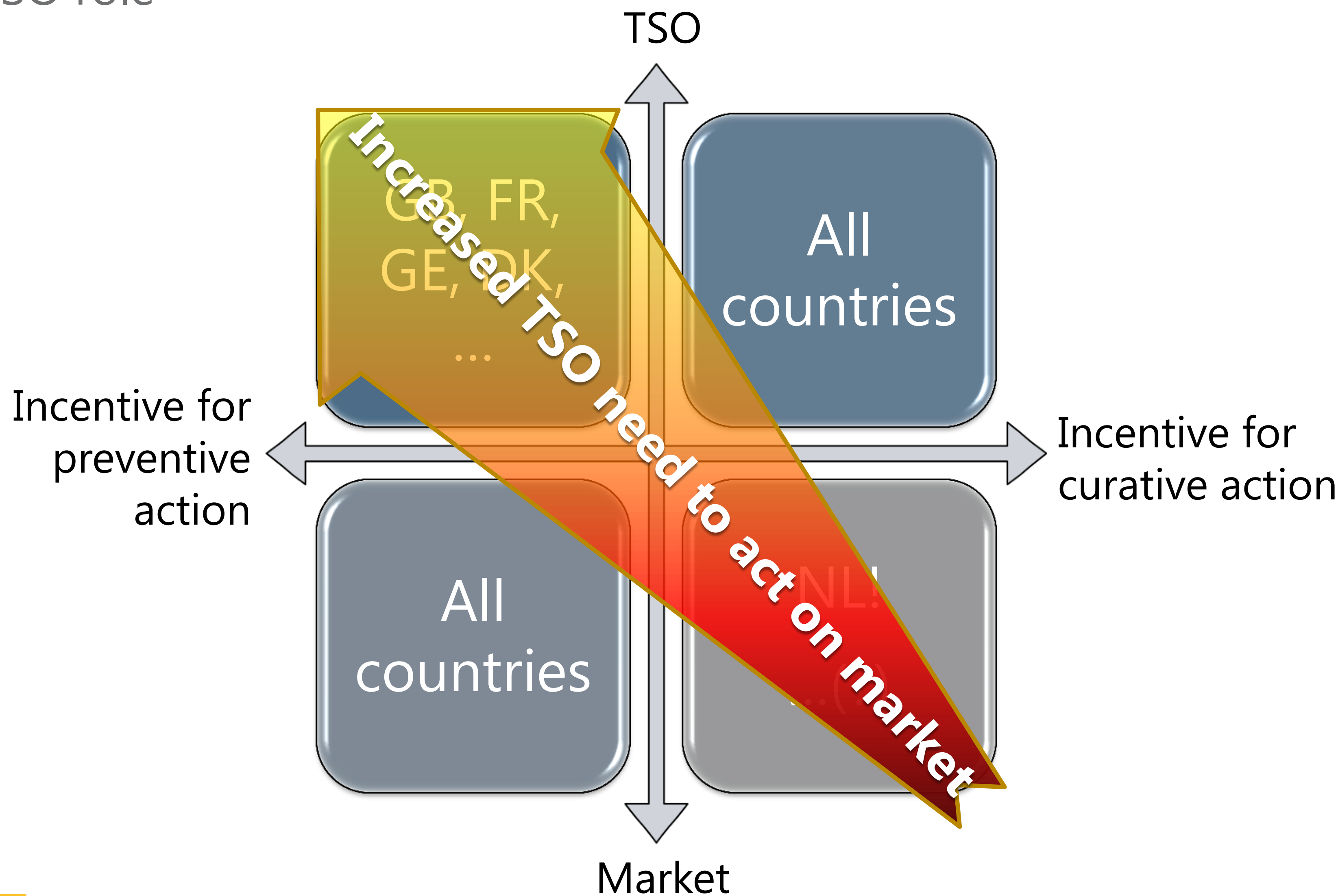
TSO role in balancing: parallel approach



TSO role


TSO
GB, FR, GE, DK, …
All countries
Incentive for preventive action
Incentive for curative action
All countries
NL!
Market
Increased TSO need to act on market

Most common combinations

- Gross Pool with integrated balancing mechanism, no bilateral trade, locational marginal pricing, central dispatch, capacity mechanisms (e.g. Ireland, Greece, most US markets, SE-Australia)
- Net pool with some integration of ancillary services, central scheduling, separate balancing mechanism (e.g. Spain, Italy, SW-Australia)
- Full bilateral energy only markets usually with a Power Exchange, seperate balancing mechanism, self-scheduling, central reserve dispatch (most other markets in EU, some exceptions in CEE, SEE)

Balancing market design in a bilateral market arrangement

- Balance between demand and supply must be kept
- A balancing mechanism is required that handles any deviations between trade positions and realtime positions of all market parties
- A balancing mechanism requires that imbalances can be allocated to and settled with accountable parties
- For this reason, balance responsibility is a necessary obligation on each market party
  - the task to specify day ahead trade positions towards the TSO (a market operator can also do it on behalf of it's clients)
  - The obligation to follow the specified trade position in realtime (this is a formal obligation, there are balancing implementations in Europe that work without it)
  - The obligation to pay for any deviation between the specified trade position and the realtime position towards the grid (must have)
- The realtime position is the measured net result of all feed-ins and all take-offs on the points in the network for which the market party carries balance responsibility

Trade acknowledgement and grid management

- To prepare the day of operation, TSOs need to check day ahead the ability of the grid to accommodate the bilateral trades agreed and take preventive actions in case of expected congestions or network security issues
- Depending on the grid, the level of detail the TSOs require may differ
- For this reason accountability for imbalances has different implementations

Accountability for imbalances (balance responsibility)

Purpose

- Enable energy transactions in an orderly fashion
- Ensure correct settlement of power transactions in a free market
- Unlink trade from physical delivery
- A priori guarantee of energy balance (not in all implementations)

Accountability for imbalances (balance responsibility)

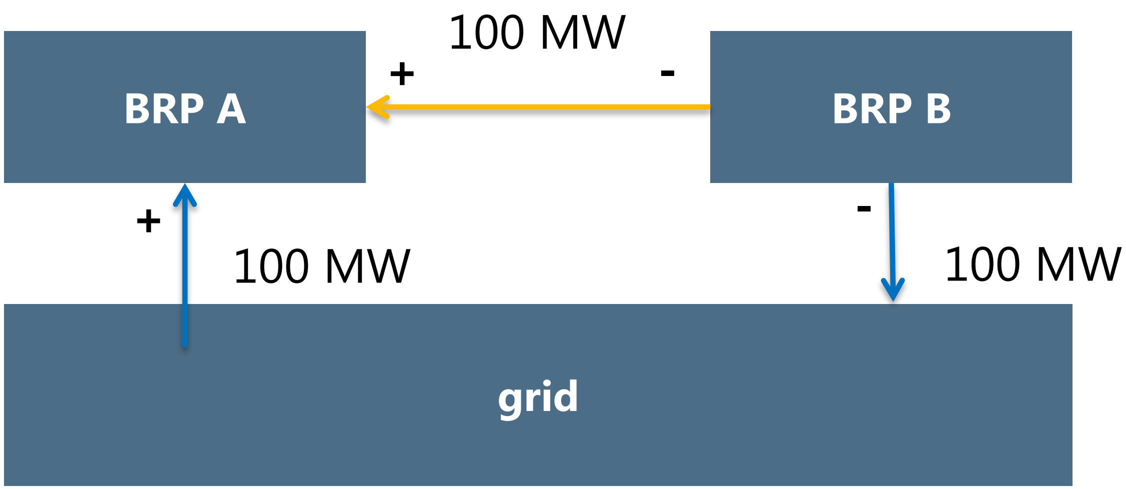
Accountability:

$$\Sigma \text{ transactions} = \text{net realtime exchange with the grid}$$

The difference is settled against an imbalance price

Trade position and realtime physical position

- Example: BRP A has a transaction of receiving 100 MW from BRP B
- Assuming no losses, this transaction can be realized only if BRP B feeds 100 MW more into the grid than it takes out



- For trade acknowledgement and imbalance settlement the TSO only needs to know the agreed transactions to determine the reference point for the BRP imbalance. In the example, BRP A submits a transaction of +100 MW with BRP B and BRP B submits a transaction of -100 MW with BRP A. The TSO assumes a + 100 MW net grid position of BRP A (take out) and -100 MW net grid position of BRP B (feed-in)

Accountability for imbalances

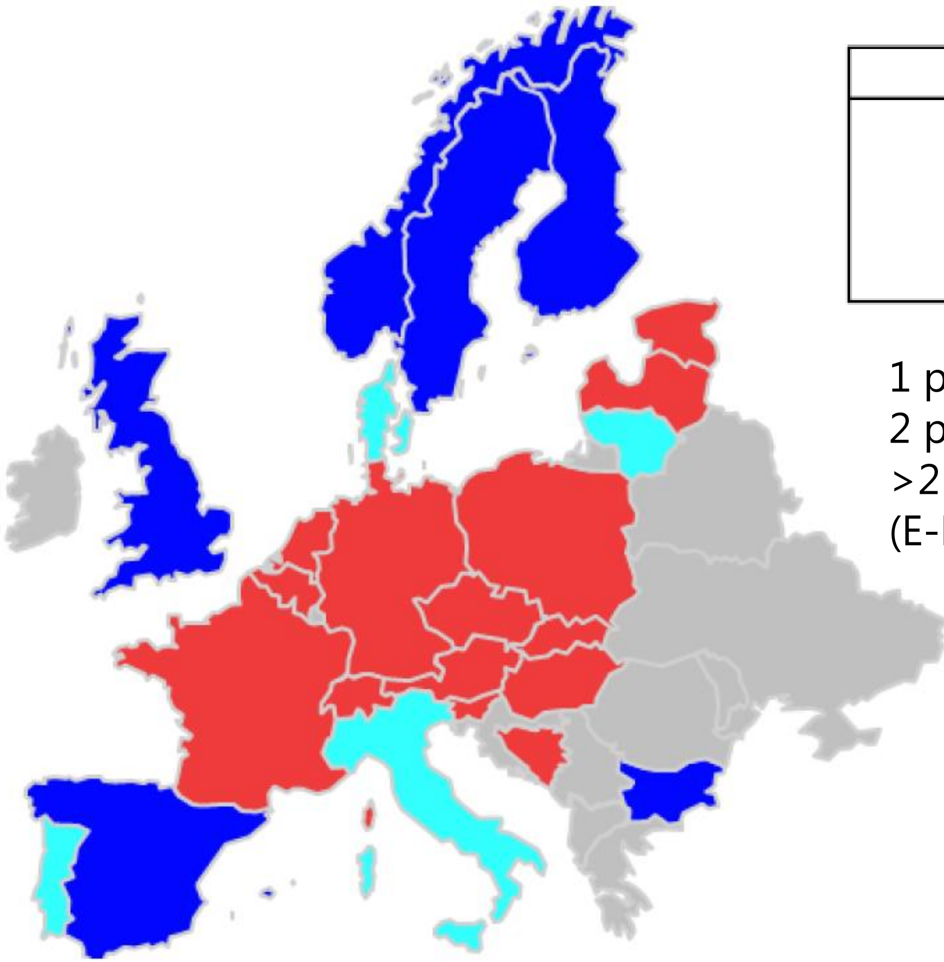
Depending on the grid, the level of detail the TSOs require may differ

For this reason accountability for imbalances has different implementations:

- Portfolio accountability
- Separate accountability for generation and demand
- Separate accountability on each point of connection to the grid
- Any combination of the above

- Usually, sequential balancing model goes allong with a separation in generation and demand accountability and sometimes accountability at each point of connection to the grid
- Portfolio accountability fits best in a parallel balancing model
- Portfolio balancing with a parallel market/TSO balancing model provides maximum dispatch freedom to the market

Imbalance portfolio's in Europe



Legend
-
1 Portfolio
2 Portfolios
> 2 Portfolios

1 portfolio: G+D+T
2 portfolio's: G+T, D+T
>2 portfolios: G, T, D or G-RES, G, T, D (E-Bridge)

Source: ENTSO-E

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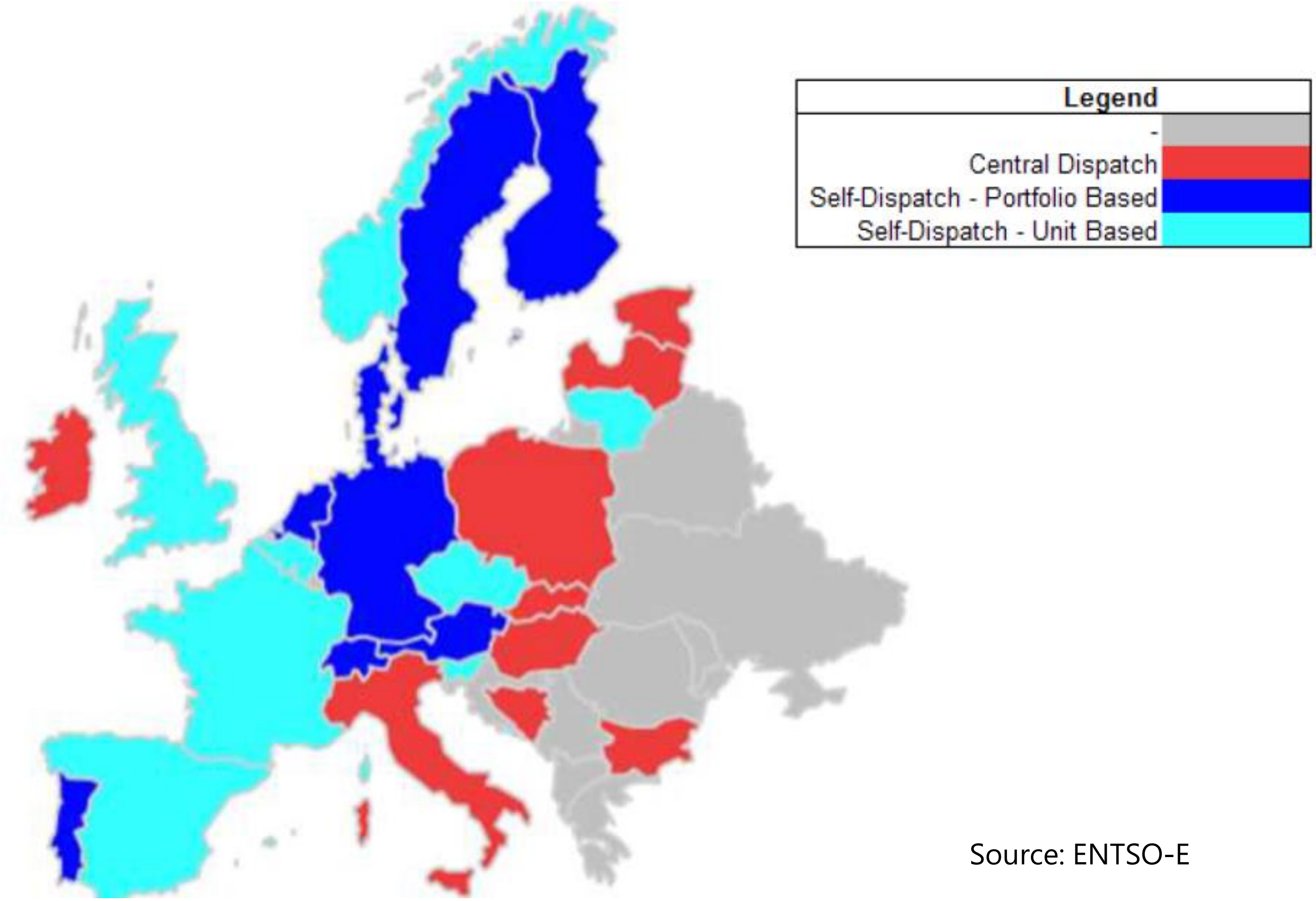
Balancing processes in place



Source: ENTSO-E

Nature of balance responsibility

Balance responsibility can include:

- The task to specify day ahead trade positions towards the TSO (any market operator can also do it on behalf of it's clients)
- The obligation to follow the specified trade position in realtime (this is a formal/legal obligation, there are balancing implementations in Europe that work without it)
- The obligation to pay for any deviation between the specified trade position and the realtime position towards the grid (financial accountability, a must have)

Generally:

- Legally anchored obligations provide more control on balance responsibility obligations and allow a minimal TSO role
- Only financial obligations enlarge the scope of the balancing task for the TSO

Nature of the balancing accountability in Europe

Legend
-
Financial Only
Legal + Financial

Source: ENTSO-E

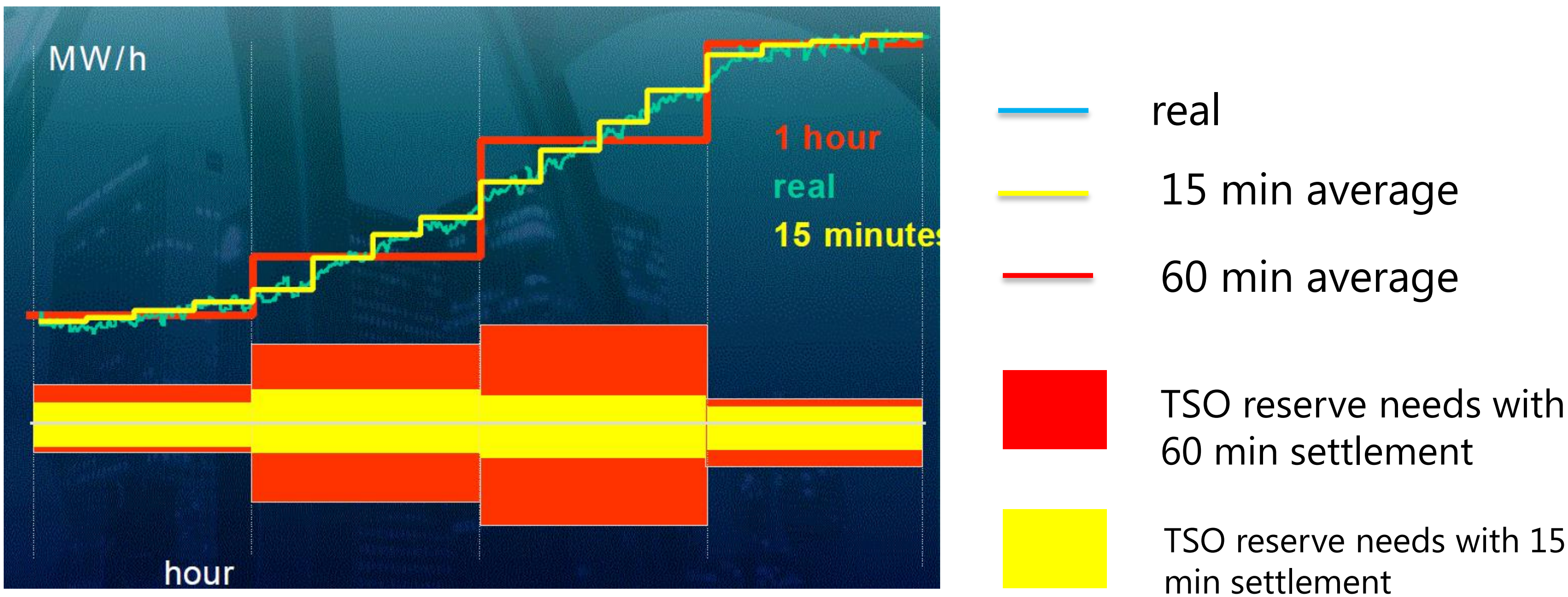
Balancing obligations – Exemptions

Legend	
-	
None	
RES	
Other	

“source: ENTSO-E

Settlement period

- The settlement period sets the maximum volume of difference between instantaneous balance and average balance
- The longer the settlement period, the higher this difference and the more the TSO needs to do during the settlement period to maintain balance



Source: R.J.L. Beune and F. Nobel, “System Balancing in the Netherlands”, ELFORSK Market Design 2001

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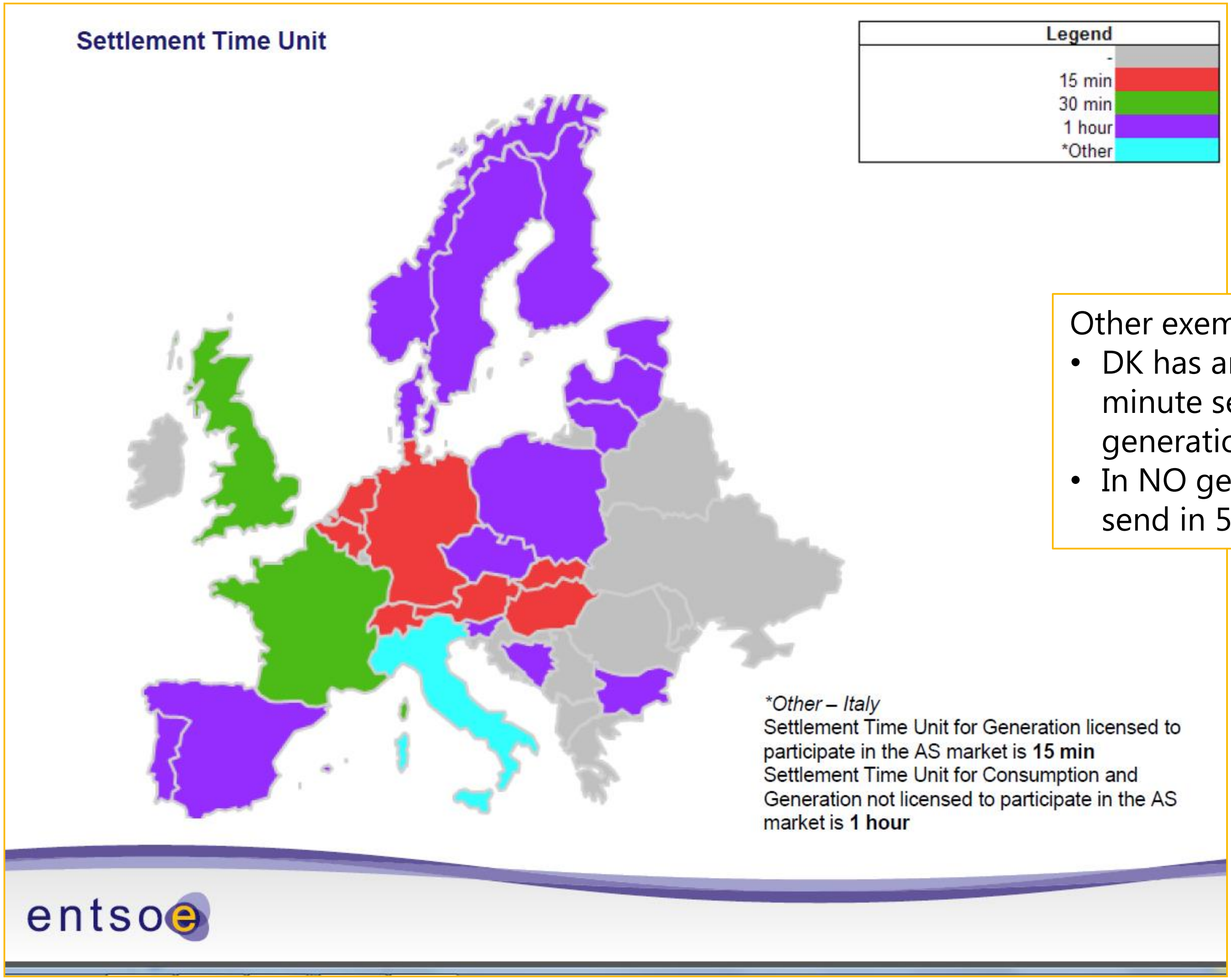
Settlement periods in Europe



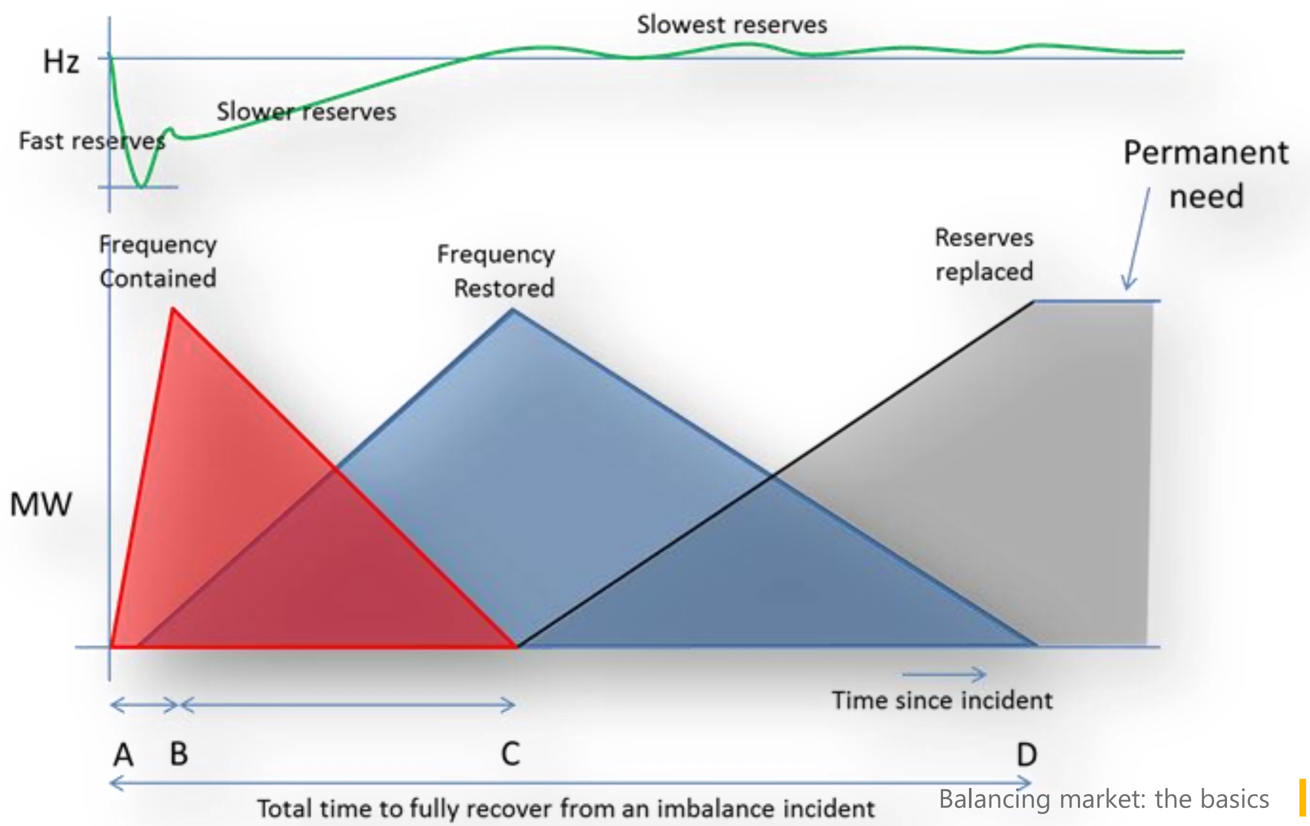
Other exemptions:

- DK has an additional 5-minute settlement for generation imbalances
- In NO generators have to send in 5 minute schedules

Source: ENTSO-E

Procurement of ancillary services for balancing

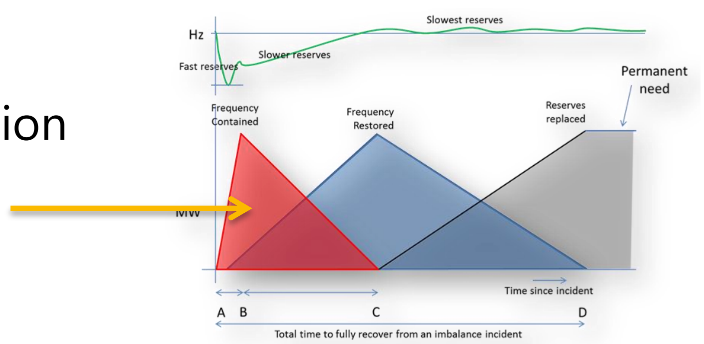
- Types of products (ENTSO-E definitions, see NC LFC&R supporting document)
  - Frequency containment reserves (FCR)
  - Frequency restoration reserves (FRR, usually separated in FRR-A and FRR-M)
  - Replacement reserves (RR)



Frequency containment reserves (FCR)

- Method: rotor controller on synchronous generator, droop settings, reserve margin
- Required volume:
  - Total volume at least equal to the largest single fault incident (usually largest generator tripping)
  - Total volume should be able to contain all incidents that can occur within time to restore frequency
- Two ways to procure capacity
  - Mandatory participation with or without renumeration, laid down in grid code, for all synchronous generating equipment
    - Renumeration could be based on capacity, energy, market price, imbalance price or tariff or there can be no renumeration
  - Reserve capacity market
    - Yearly: bilateral contract; tender or auction
    - Weekly/Daily: auction

FCR



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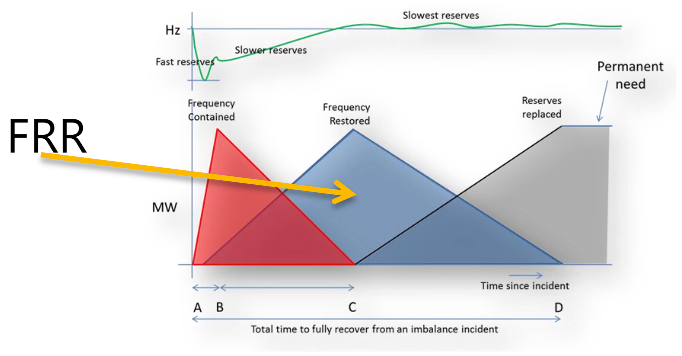
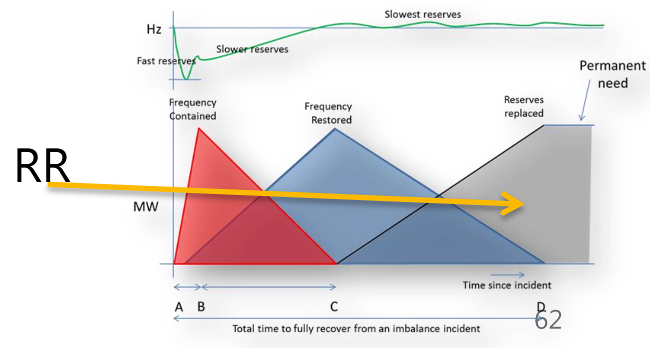
Frequency restoration reserve (FRR)

- Requires a manual or automated instruction from the TSO to regulate up- or down
- On the European continent and in Scandinavia there is a combination of manually (FRR-M) and automatically (FRR-A) activated FRR
- Procurement of FRR reserves (capacity)
  - Usually FRR-A: yearly contracting or daily auctions
  - Sometimes also for FRR-M (manually activated)
  - Remuneration: pay as bid
- Procurement of FRR-M balancing energy mostly through submission of balancing energy bids to a bid ladder, with volume and energy price; seperate for up- and downward regulation



Replacement reserves



- These are reserves which do generally allow (or require) an activation time of more than the time to restore frequency
- Contrary to FCR and FRR, replacement reserves have no well defined “end of activation” criterion
  - FCR activation ends as soon as frequency is restored
  - FRR activation ends as soon as replacement reserves have taken over
  - Replacement reserve activation can only end through a market reaction
- If the balancing mechanism contains sufficient incentives for the market RR activation can be left to the market in order to avoid market distortions by the TSO
- This requires good transparency and facilitation of the market from the TSO
- Alternatively the RR activation function of the TSO could be designed as subject to the same market rules as any other market party
  - Subject to imbalance charges which should not be renumerated through the tariff

FRR-A reserve capacity procurement, reserve bidding and activation process

This requires

- Capacity procurement; seperate for upward and downward FCR (Grid Code requirement)
- Bidding of the reserve on a common bid ladder (contracted and non-contracted capacities)
- Selection of reserves for the automatic generation control (AGC) by the TSO
- Activation of the reserves according to energy price merit order by the AGC
- All non-deliveries are subject to imbalance settlement, but as this concerns average imbalance during the settlement period additional incentives are required
  - Monitoring of the reaction of the FRR-A service provider (operational measurements, special monitoring software and staff)
  - Penalty system in case of non-delivery for contracted capacities

FRR-M reserve bidding and activation process

- The Scandinavian system can serve as a good example of a balancing mechanism, based on FCR and FRR-M only:
  - FRR-M product characteristic:
    - MW of upward or downward regulation power that can be activated at any level during the settlement period
    - Price paid for activation is the price of the marginal bid activated in bid price merit order
  - Recently the Nordic TSOs started a pilot project to introduce AGC and FRR-A reserves

- Continental Europe systems use a combination of FRR-A and FRR-M
- Selection, activation and pricing is done in different ways

Pricing of reserves

- Pay as bid
- Pay marginal
- Regulated price

- Usually pay as bid is applied for reserve capacities
- All methods occur for activated balancing energy

Imbalance pricing

- Design criteria
  - Right imbalance price
  - No incentives for intentional imbalances
  - Zero net result for the TSO

Right imbalance price / balancing incentives

1. Imbalance energy should on average be more expensive than wholesale market energy
2. Control energy should on average be more expensive than wholesale market energy
3. Control energy should on average not be more expensive than imbalance energy

- If 1. is not satisfied, market parties would buy / sell imbalances with the TSO rather than through the wholesale market
- If 2. is not satisfied, there is no incentive to provide control energy to the TSO
- If 3. is not satisfied, there is no incentive to provide the requested control energy

Zero net result for the TSO

- Because the absolute volume of imbalances of the market is larger than the absolute volume of system imbalances (which is closely related to the activated balancing energy), TSOs may have a positive result from the difference in imbalance settlement and balancing costs
- Two methods to get a zero net result for the TSO:
  - By determining the imbalance price ex-post accordingly
    - This limits transparency and the possibility of quick (even realtime) publication of imbalance prices
  - By spill-over to next year's tariff

Imbalance pricing

One price or two-price systems

- A one price system has a single imbalance price for system shortage situations and a single imbalance price for system surplus situations
- A two-price system has two imbalance prices for system shortage situations and two imbalance prices for system surplus situations, where the price charged depends on the BRP imbalance helping the system balance or not

One price system

One price system: a single imbalance price for each system imbalance state

- The system imbalance state is determined from the net system imbalance over the settlement period: short or long
- If the net system imbalance is a shortage, the imbalance price is related to the average price paid for the activated upward regulation bids
- If the net system imbalance is a surplus, the imbalance price is related to the average price paid for the activated downward regulation bids
- BRPs pay the imbalance price in case of a shortage and receive the imbalance price in case of surplus

	System short	System long
BRP short pays	APu	APd
BRP long receives	APu	APd

Notes:
In case of pay marginal bid pricing, the average price paid turns into the marginal price paid
In case of negative prices, receive APu or Apd turns into pay –Apu respectively pay -APd

Two price system

- two prices for each system imbalance state:
  - imbalance prices for helpful imbalances are set to the wholesale market price
  - Imbalance prices for harmful imbalances are set to the average price of activated regulating bids and an optional surcharge/penalty
- Argumentation for a two price system is that helpful imbalances have been provided unintentionally and should not receive the same price as the balance providers
- This system is usually applied with a sequential balancing model as it provides no incentives to contribute to the system balance outside the TSO single buyer balancing market

	System short	System long
BRP short pays	$APu*(1+penalty_u)$	MCP
BRP long receives	MCP	$APd/(1+penaly_d)$

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Hybrid pricing

- A one-price system always gives a self-balancing incentive, even in situations where it would be better not to give an incentive
- A two-price system awards active balance service provision above passive balance service provision, where passive balance service provision may have lower transaction costs
- Hybrid pricing allows to take the best of the two:
  - One price in situations of a single system imbalance direction during the whole settlement period
  - Two prices in situations of an alternating system imbalance direction during the whole settlement period*)

	System short	System long	System dual
BRP short pays	APu	APd	APu
BRP long receives	APu	APd	APd

*) dual imbalance states are less frequent in systems with a smaller settlement period, where such a hybrid system usually behaves as a single pricing system, e.g. in NL 80-90% of the time the system has a single imbalance state

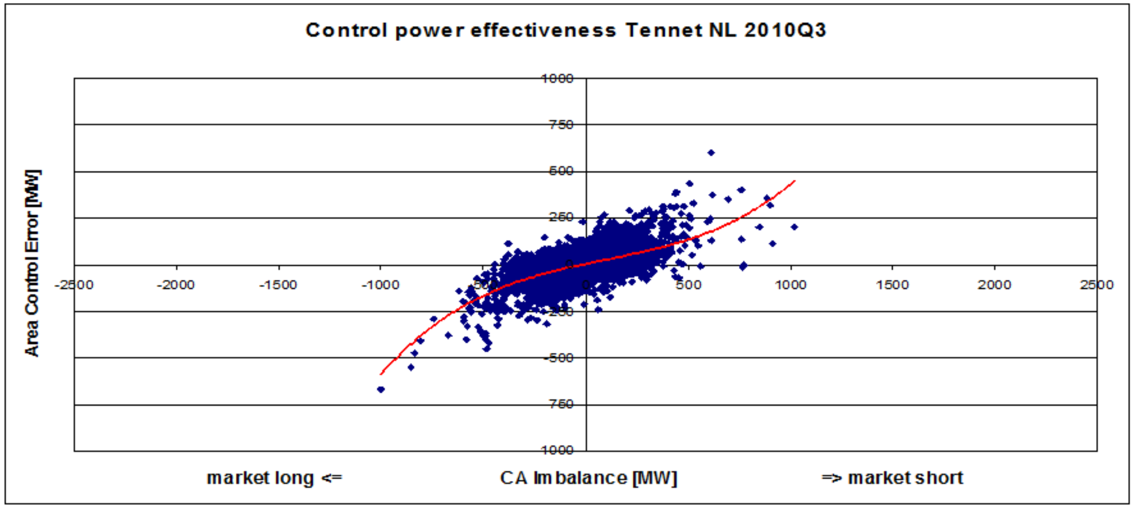
Comparison of balancing systems: NL and DE

	NL	DE
Reserve Capacity Auction	SR+/-: annual (symmetric), *within* residual market Dedicated TR+: annual; *supplementary to market*	SR+/-: monthly, weekly (+/- separately) TR: daily (+/- separately)
Contracted Volumes (MW)	Minimum (according to OH)	*Total* (after analytical model)
Available Capacity (MW)	Residual Market + supplements	Contracted Volume, *no other bids allowed*
Firmness Bids	GCT 1h	At Contract
Publication Bidladder data	Day ahead, Intraday updates	After Auctions
Control Energy Payments	Uniform, marginal	Pay-as-bid
Publication Activation data	Real time, minute updates, volume + marginal price	-
Imbalance Price	2-price, marginal price based, collapses to 1-price ca. 80-90%	1-price, cost-based
Publication Imbalance Price	Real time indication from publication activation data; D+1	Several weeks

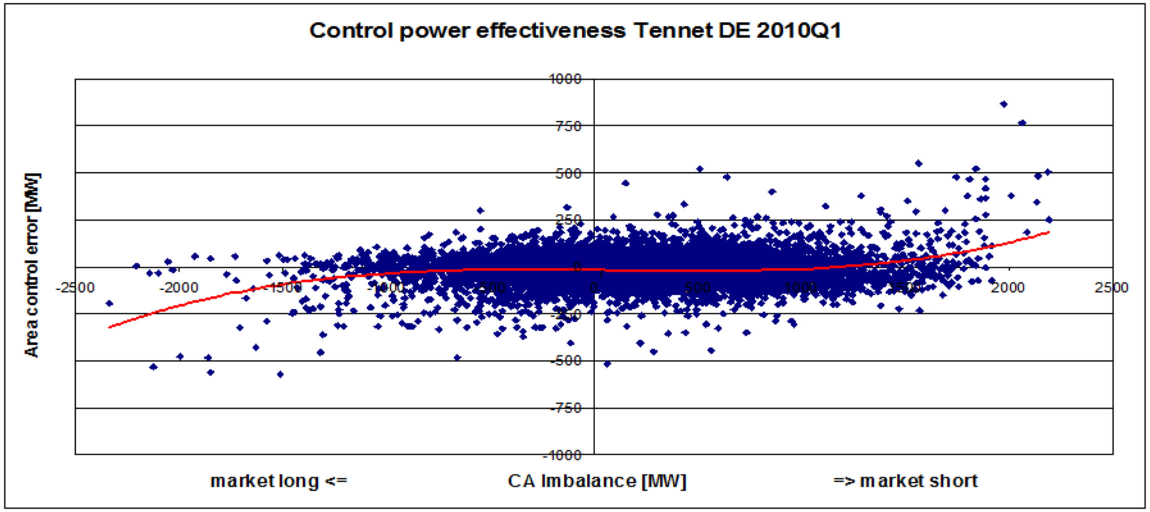
Source: TenneT

Control Effectivity NL, TenneT DE

system imbalance (MW)



system imbalance (MW)



Source: TenneT

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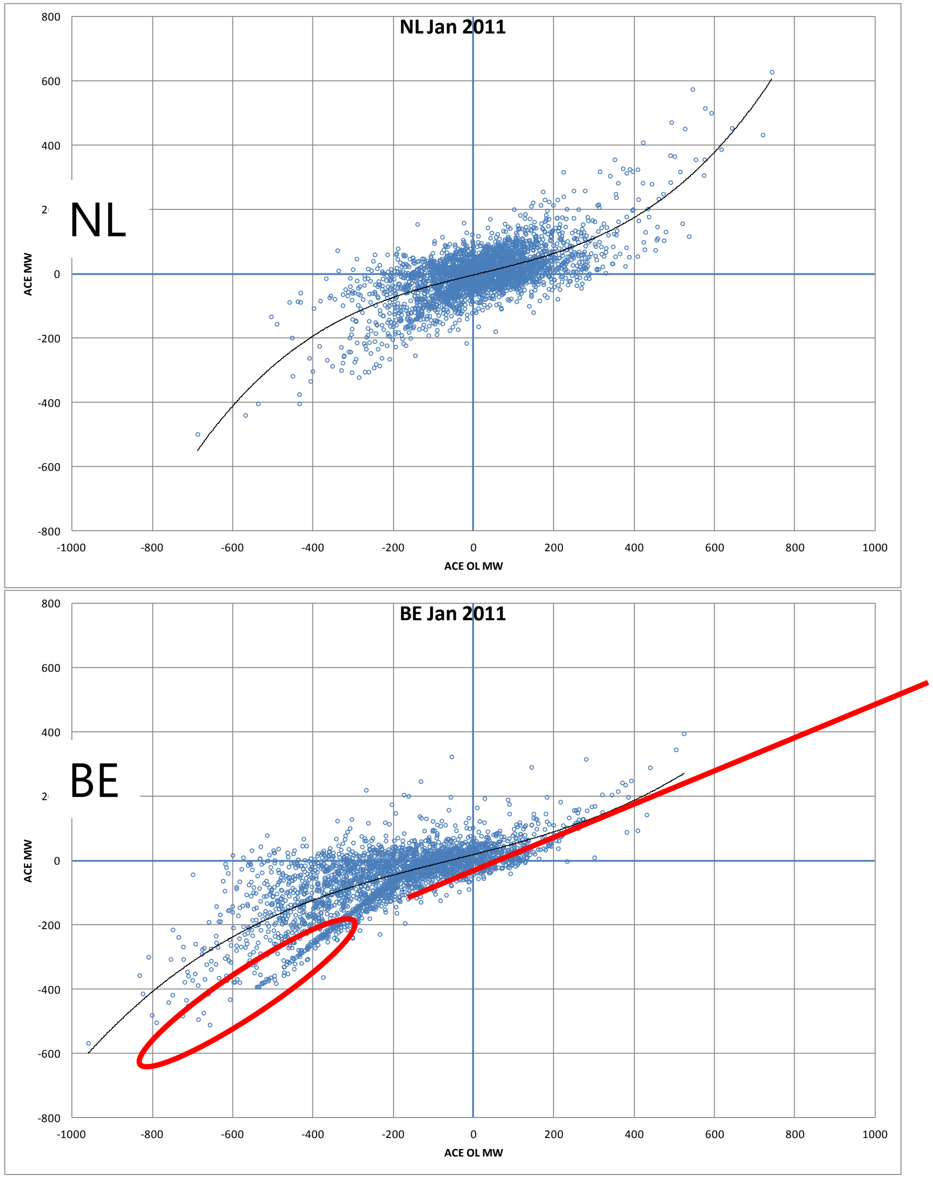
Control Effectivity NL, B



Control limit often reached

Cause:

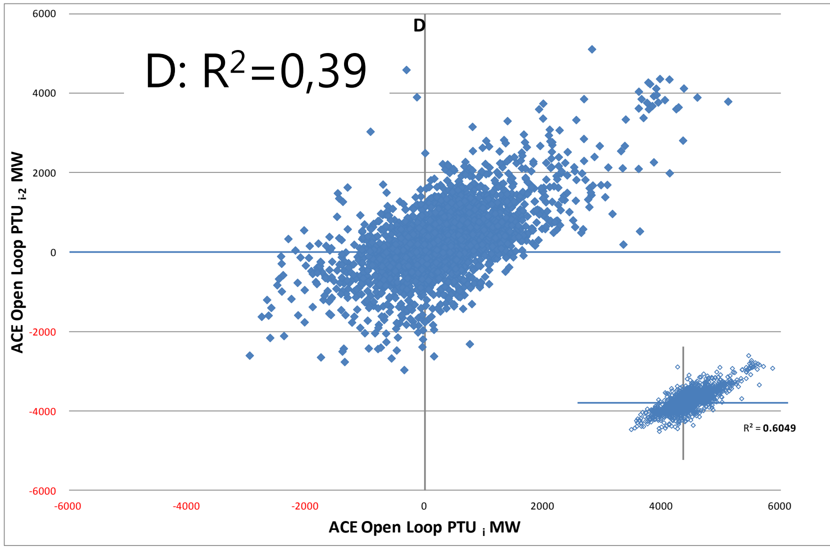
- No reward for passive contribution
- Cap on bidprice

Nowadays corrected:

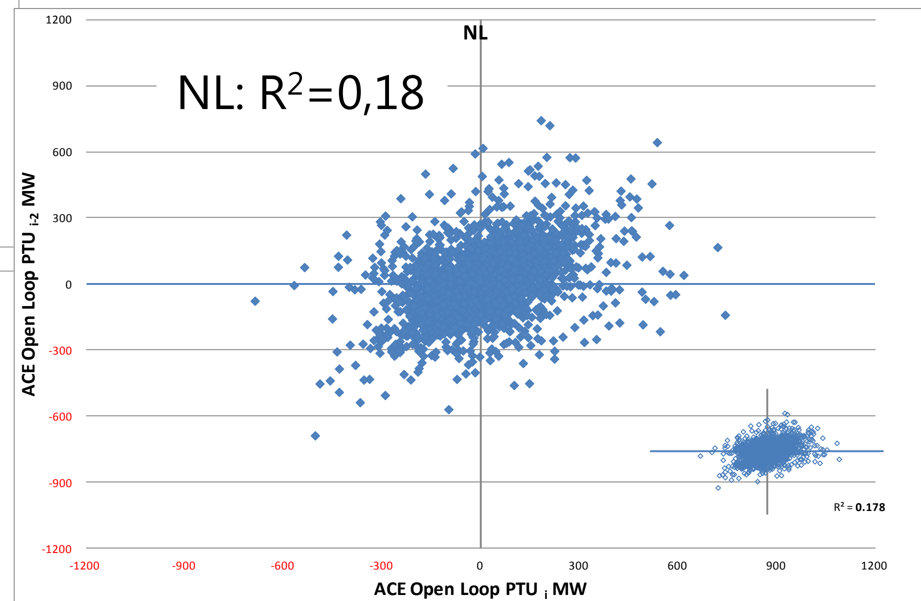
- Passive contribution rewarded
- No cap on bidprice

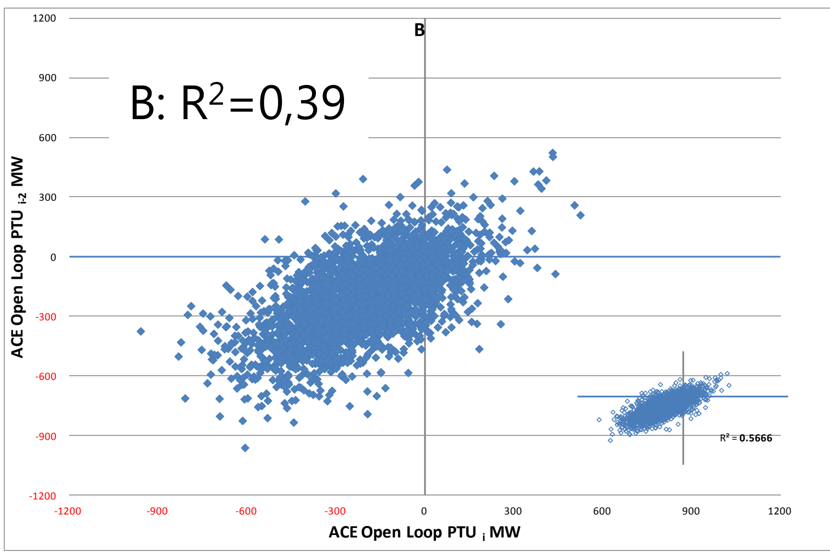
Source: TenneT

Market Imbalance persistency



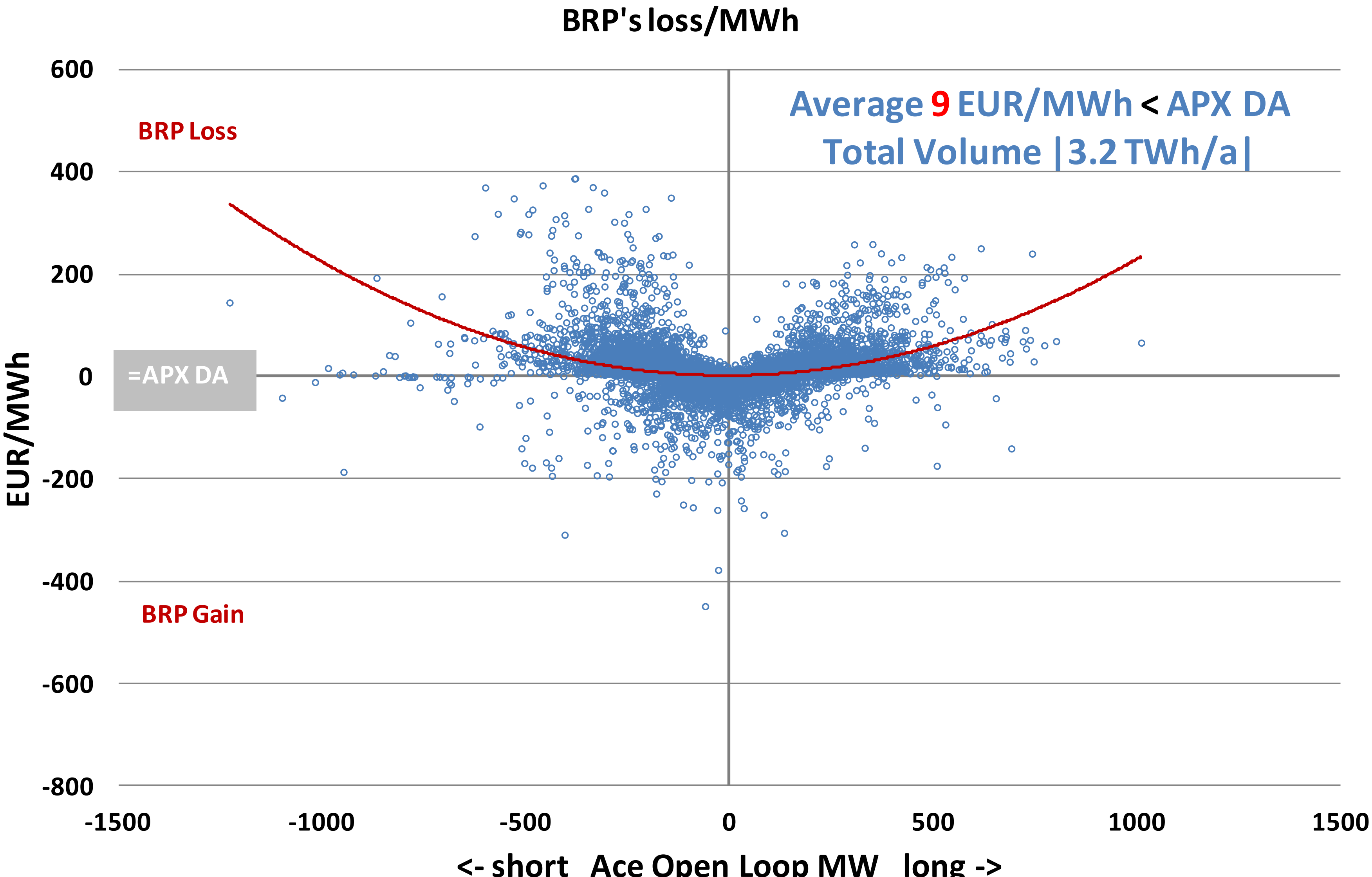
The higher R^2, the lower incentive for passive contribution





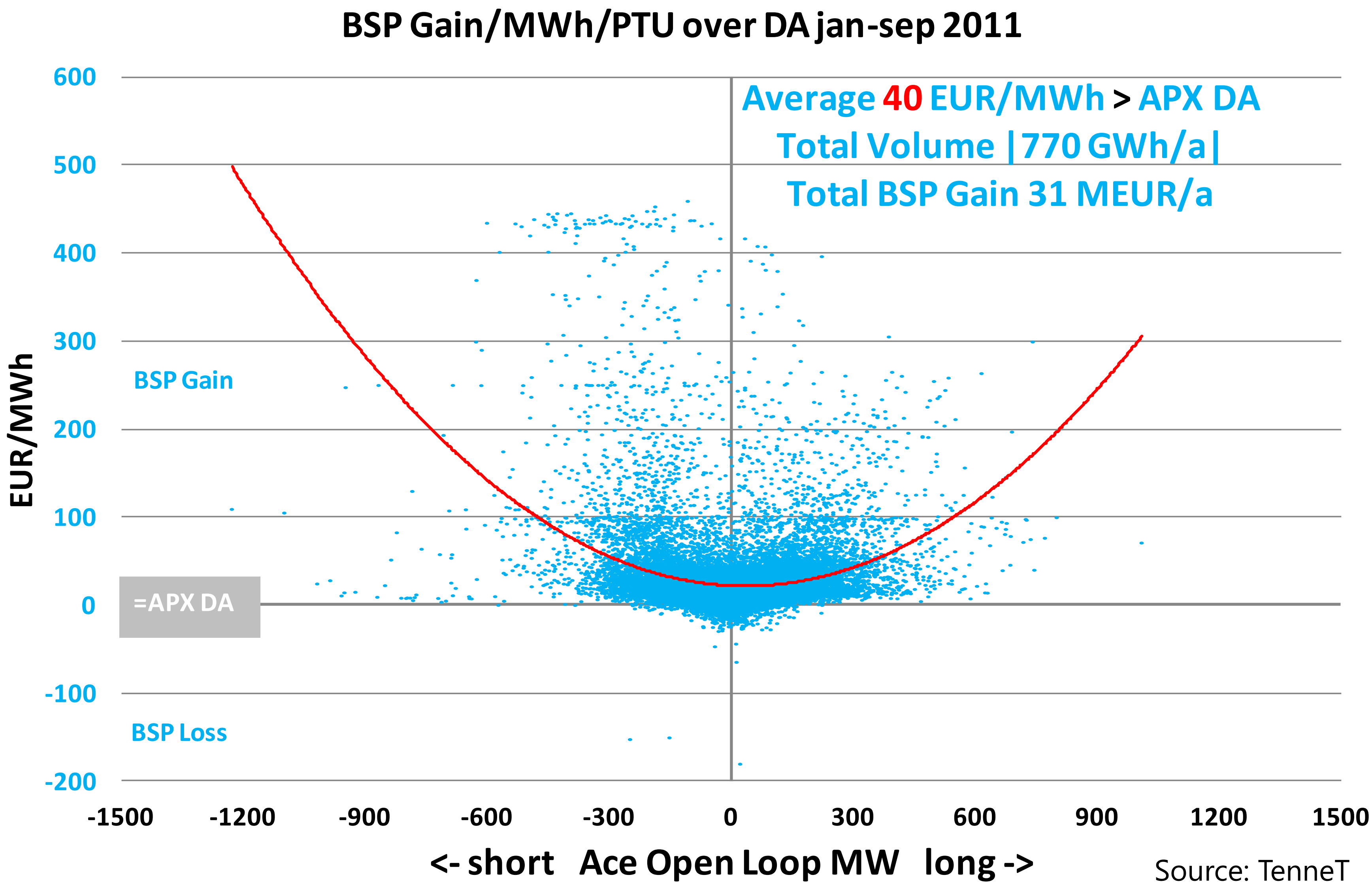
Source: TenneT

Imbalance on average less attractive than wholesale market



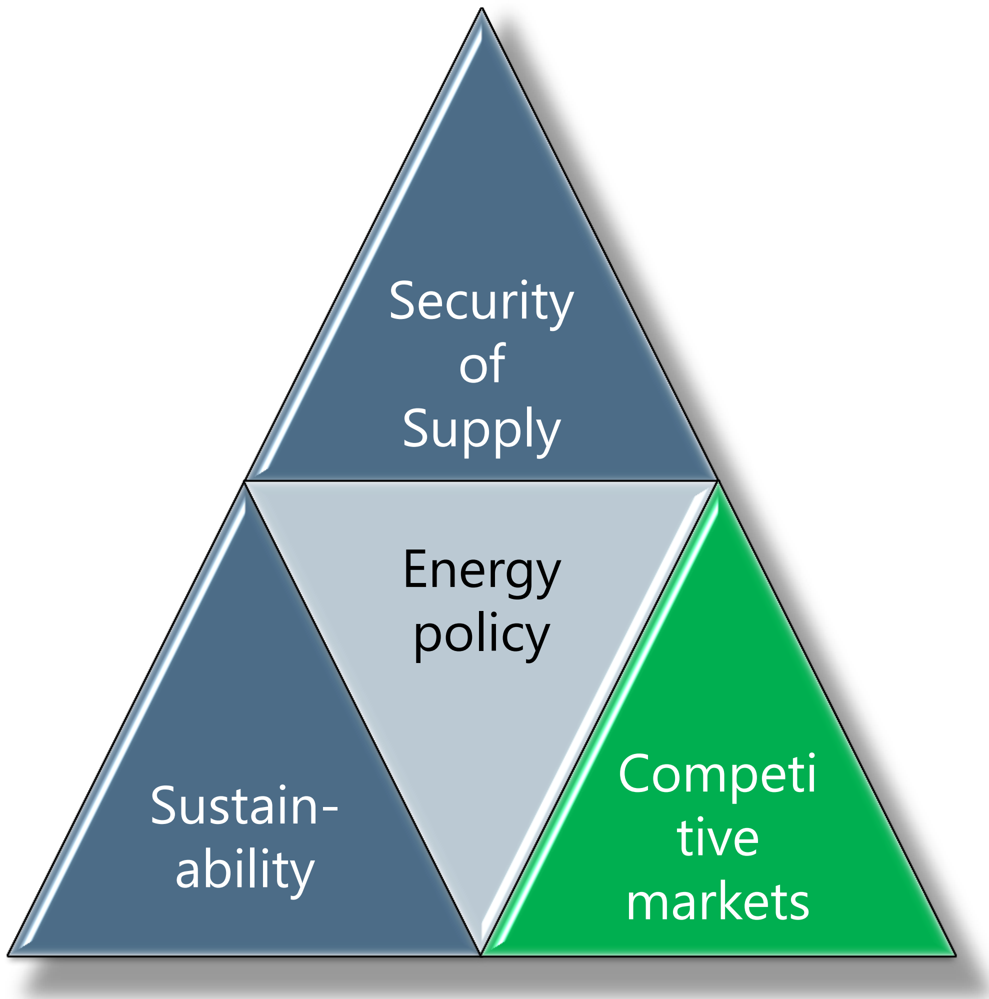
Source: TenneT

Control energy delivery on average more attractive than wholesale market



Source: TenneT

Three cornerstones of European energy policy



XB Balancing mechanism developments / markets

- Multilat. TSO-TSO model with CMO
- Multilat. TSO-TSO model without CMO
- bilateral TSO-TSO model
- TSO-BRP model
- Mechanism under development

- 1 - TSO-TSO balancing UK-FR (BALIT)
- 1a & 1b – Interim solutions FR-SP and PT-SP (possible extension of BALIT)
- 1c – enduring solution PT-SP-FR I/C
- 2 – SO balancing over Moyle I/C
- 3 – SO balancing over East West I/C
- 4 – development of arrangements over Britned
- 5 – Nordic Balancing Market
- 5a – Possible extension of Nordic Market
- 6 – Exchange of balancing energy between CH&DE generators and FR TSO
- 7 – development of AT-DE BRP-TSO model
- 8 – development of CZ-SK balancing market
- 9 – developments in Central Southern Europe

European Network Code for Balancing: main developments

Harmonisation into three system balancing processes

- Frequency containment; Typical product: primary reserves
- Frequency restoration; Typical products secondary, tertiary and emergency reserves
- Replacement of reserves

TSO system balance coordination

- Control area surpluses and shortages leveled out: diminish need for TSO control action

Common Merit Order (CMO)

- Activating the cheapest bid of all involved control areas, provided capacity is available

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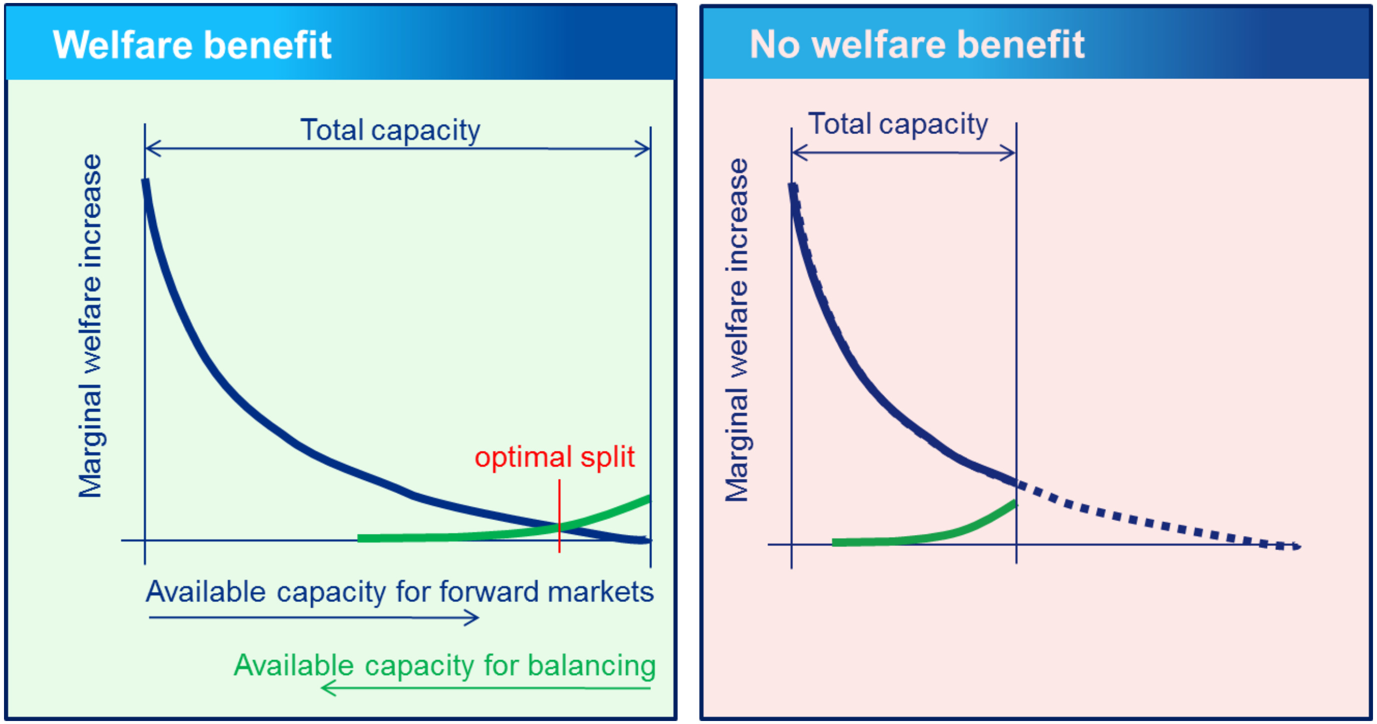
European FG on Balancing: capacity reservation

Reserving cross-border capacity for Balancing

- Generally not allowed
- Exceptions are possible, provided welfare benefits can be proven



European Balancing Code: basic concepts

- Imbalance Netting and Common Merit Order
- Standard products
- Coordinated Balancing Areas
- Activation Optimization Function

What is imbalance netting?

- We have seen in part I as formula for the TSO system imbalance

  $ACE_i = \Delta P_i + \lambda_i.\Delta f$

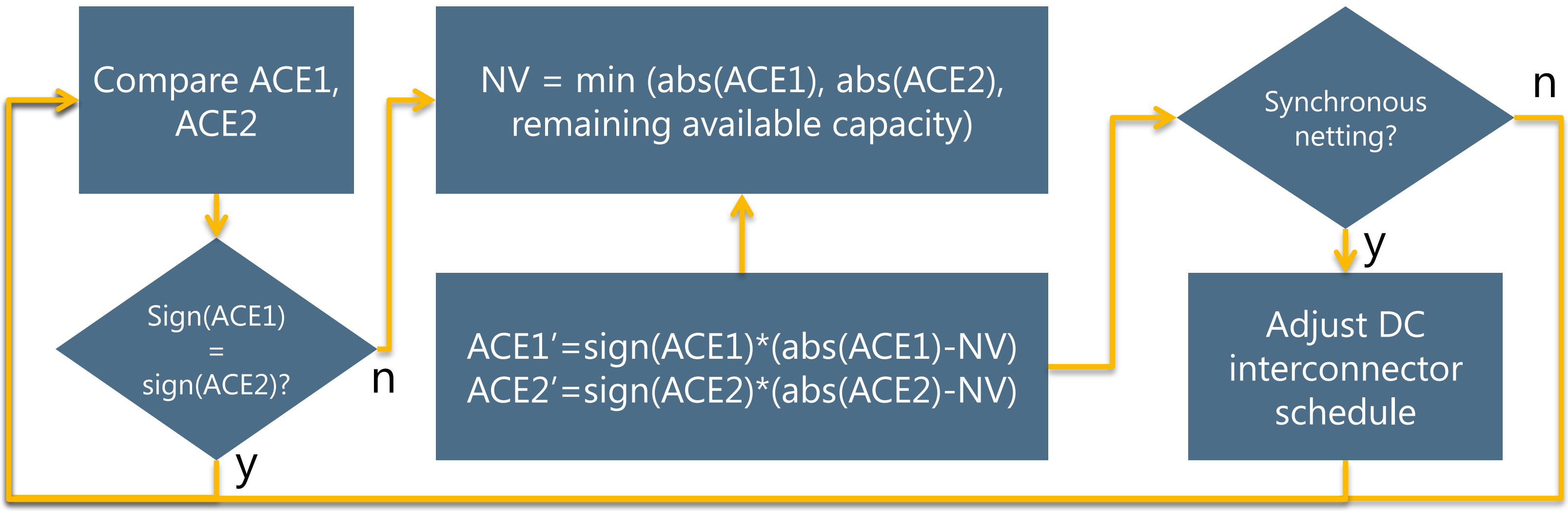
- The goal of imbalance netting is to reduce system imbalances with different signs to prevent unneccessary frequency control actions

- This reduces the total need for activation of balancing energy

- There is a principle difference between imbalance netting within a synchronous system and between synchronous systems
  - Imbalance netting within a (AC interconnected) synchronous system is an administrative action on the ACEs concerned and does not involve the exchange of any energy
  - Imbalance netting between (DC interconnected) sysnchronous systems requires a physical exchange of the imbalance reduction over the DC interconnectors

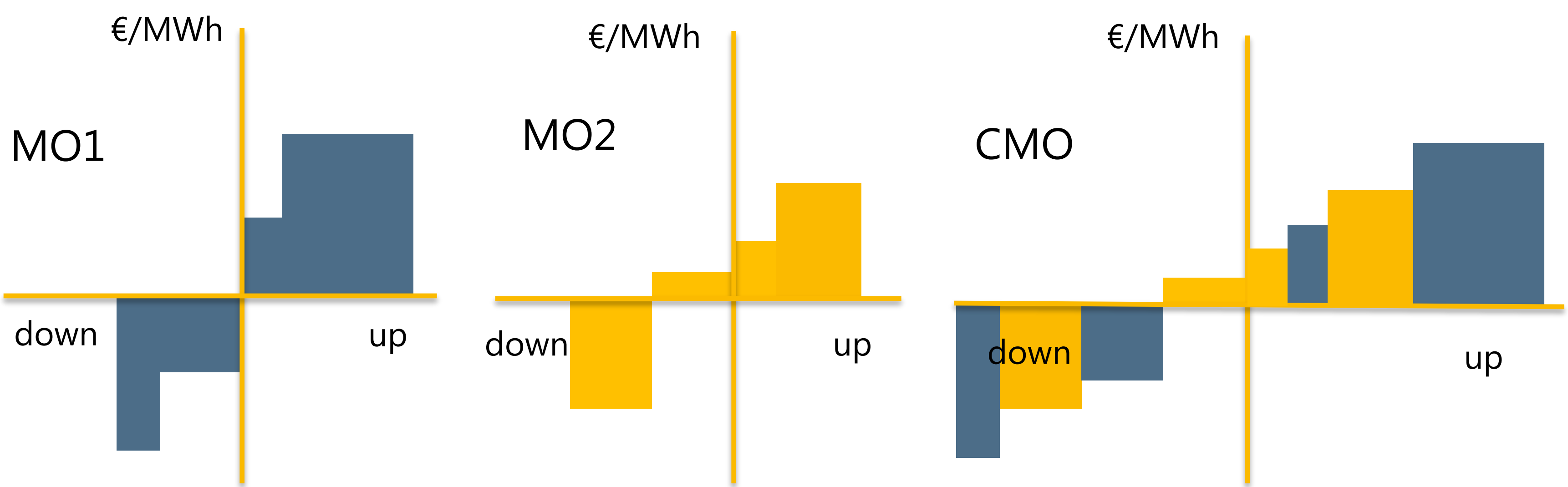
Imbalance netting: general procedure between two control areas

- Step 1: compare ACEs,
  - if same sign, do nothing
- Step 2: Reduce the ACE with the lowest absolute value to zero, reduce the absolute value of the highest ACE with the absolute value of the lowest absolute ACE but keep the sign (cap reduction with available remaining transmission capacity)
- Step 3: if netting between synchronous systems: adjust the DC interconnector exchange with the reduced ACE
- Continuously repeat from step 1

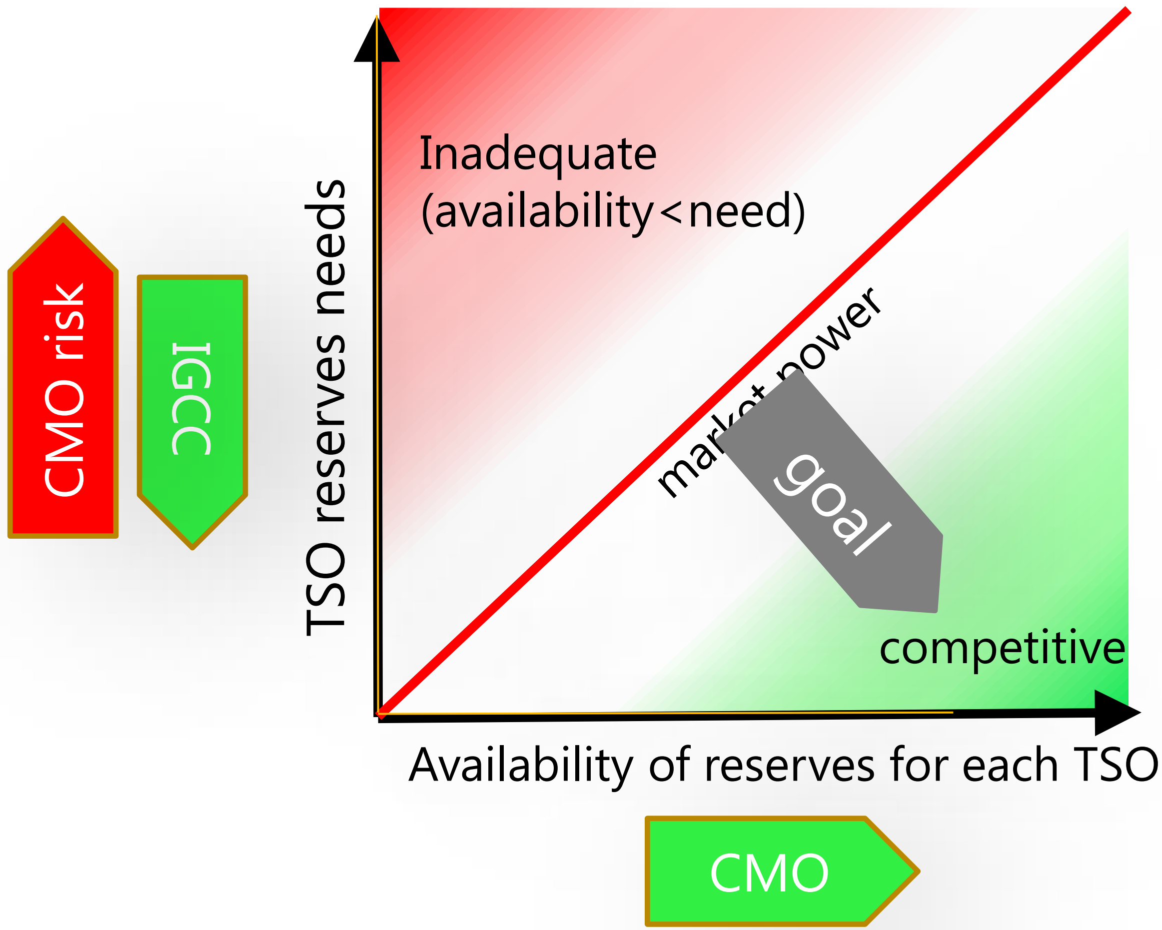


Common merit order

- A common merit order implies the integration of the merit orders of each control area into a single integrated merit order with the purpose of not only sharing the resources but also sharing the system imbalances
- Imbalance netting is a prerequisite for a common merit order



Imbalance netting and Common Merit Order



Source: TenneT

Conditon for CMO: harmonized balancing market designs

Standard Products

- A standard product is a product which is standardized in the product specifications
- Through Europe, different products and product characteristics are applied for the reserves in the three balancing processes
- Common issue:
  - Product time period

Frequency Containment Reserves

- Droop settings
- Reaction speed
- Deadband

Frequency Restoration Reserves

- FRR-A, automatically activated
  - Ramping speed
- FRR-M, manually activated
  - Activation time
  - Flexible versus fill or kill

Replacement reserves

- Activation time
- End of activtion
- Flexible versus fill or kill

Overview of differences in Europe

Sync. Area	Process	Product	Activation	Local/Central	Dynamic/ Static	Full Activation Time
BALTIC	Frequency Containment	Primary Reserve	Auto	Local	D	30 s
Cyprus	Frequency Containment	Primary Reserve	Auto	Local	D	20 s
Iceland	Frequency Containment	Primary Control Reserve	Auto	Local	D	variable
Ireland	Frequency Containment	Primary operating reserve	Auto	Local	D/S	5 s
Ireland	Frequency Containment	Secondary operating reserve	Auto	Local	D/S	15 s
NORDIC	Frequency Containment	FNR (FCR N)	Auto	Local	D	120 s -180 s
NORDIC	Frequency Containment	FDR (FCR D)	Auto	Local	D	30 s
RG CE	Frequency Containment	Primary Control Reserve	Auto	Local	D	30 s
UK	Frequency Containment	Frequency response dynamic	Auto	Local	D	Primary 10 s / Secondary 30 s
UK	Frequency Containment	Frequency response static	Auto	Local	S	variable
BALTIC	Frequency Restoration	Secondary emergency reserve	Manual	Central	S	15 Min
Cyprus	Frequency Restoration	Secondary Control Reserve	Auto/Manual	Local/Central	D/S	5 Min
Iceland	Frequency Restoration	Regulating power	Manual	Central	S	10 Min
Ireland	Frequency Restoration	Tertiary operational reserve 1	Auto/Manual	Local/Central	D/S	90 s
Ireland	Frequency Restoration	Tertiary operational reserve 2	Manual	Central	S	5 Min
Ireland	Frequency Restoration	Replacement reserves	Manual	Central	S	20 Min
NORDIC	Frequency Restoration	Regulating power	Manual	Central	S	15 Min
RG CE	Frequency Restoration	Secondary Control Reserve	Auto	Central	D	≤ 15 Min
RG CE	Frequency Restoration	Direct activated Tertiary Control Reserve	Manual	Central	S	≤ 15 Min
UK	Frequency Restoration	Various Products	Manual	D/S	N/A	variable
BALTIC	Replacement	Tertiary (cold) reserve	Manual	Central	S	12 h
Cyprus	Replacement	Replacement reserves	Manual	Central	S	20 min
Iceland	Replacement	Regulating power	Manual	Central	S	10 Min
Ireland	Replacement	Replacement reserves	Manual	Central	S	20 Min
NORDIC	Replacement	Regulating power	Manual	Central	S	15 Min
RG CE	Replacement	Schedule activated Tertiary Control Reserve	Manual	Central	S	individual
RG CE	Replacement	Direct activated Tertiary Control Reserve	Manual	Central	S	individual
UK	Replacement	Various Products but the main one is Short Term Operating Reserve (STOR)	Manual	D/S	N/A	from 20 min to 4 h

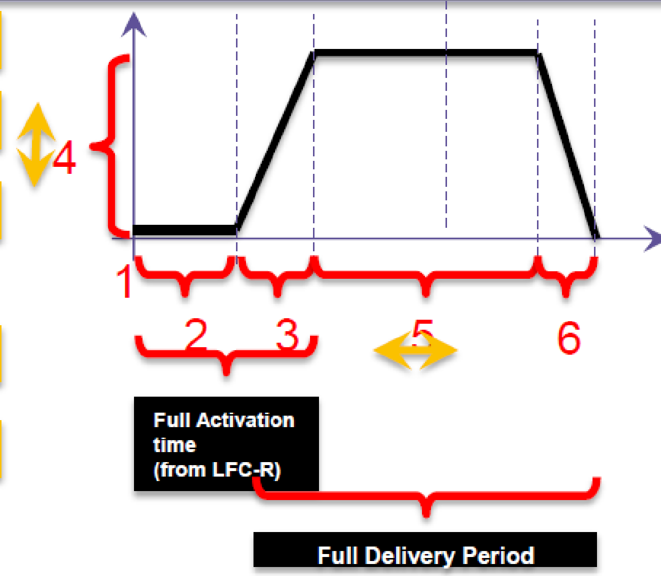
Source: ENTSO-E

Minimum standard product characteristics according to NCEB

Standard Products

Common at synchronous area level

- 1- Request time
- 2- Preparation period
- 3- Ramping period
- 4- Min & max bid size
- 5- Min & max delivery period
- 6- Deactivation period



- Mode of activation
- Divisibility
- Location
- Validity period

Specific Products

Additional or other caracteristics

Control area level

Source: ENTSO-E

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Coordinated Balancing Areas (CoBA)

- A coordinated Balancing Area is defined in the ENCEB as a group of at least two TSOs sharing at least one standard product
- Prerequisite for this sharing is the imbalance netting
- The Nordic regulating power market (4 TSOs) and the German regulating power market (4 TSOs) are examples of embryonic CoBA's
  - They already share standard products for each category today
  - They perform imbalance netting today
  - Their balancing markets have been harmonized to a large extent
- Challenge is the extension to adjacent TSOs, either by exchange of service (easiest) or sharing (most complex)
  - Product compatibility
  - TSO mandates
  - Compatibility of procurement methods
  - Pricing compatibility

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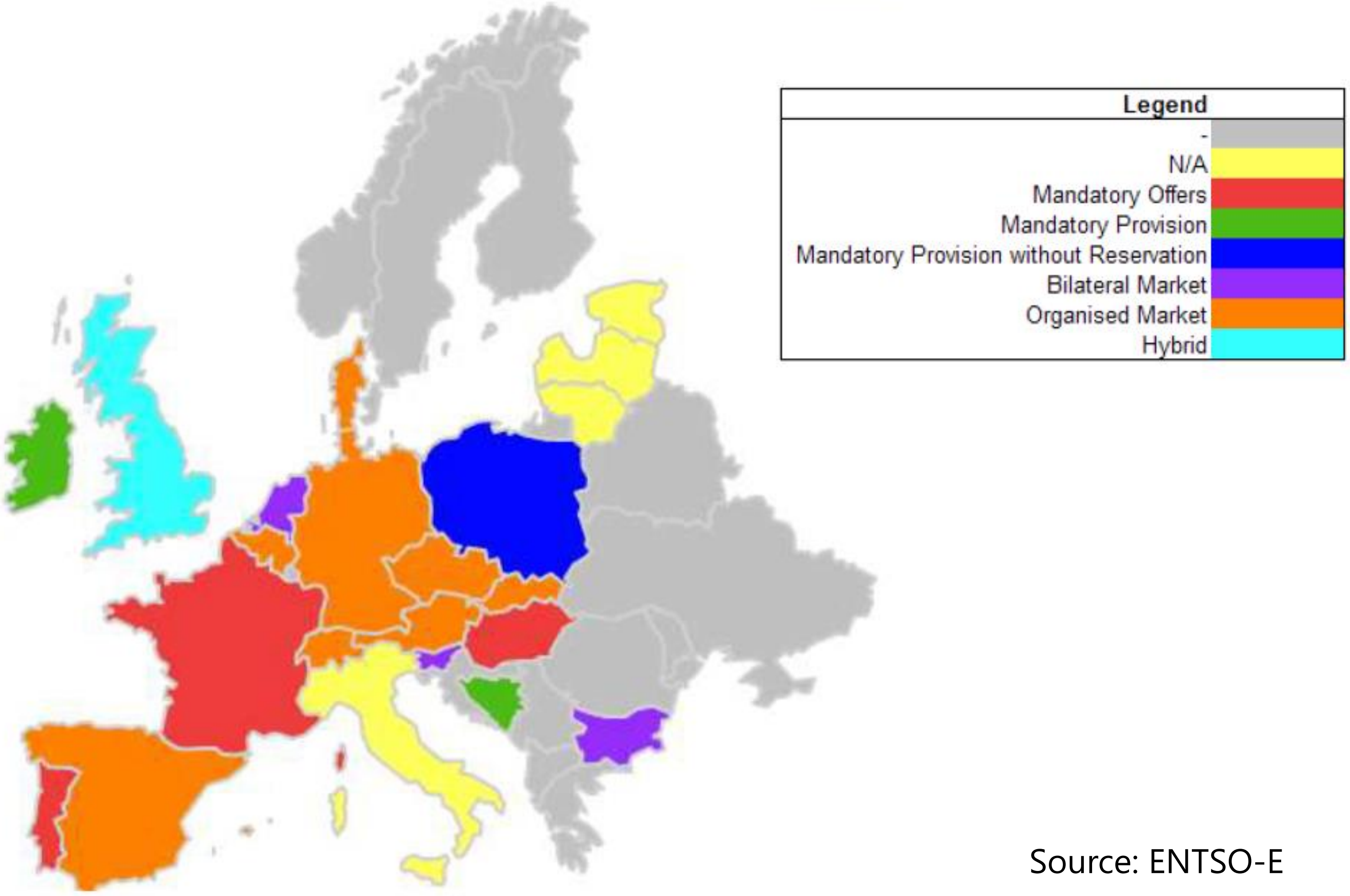
FRR-A capacity procurement schemes in Europe



Source: ENTSO-E

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Example of a pricing incompatibility

- In the Dutch system, FRR-M bids are paid marginal and the imbalance price is equal to the marginally activated bid
- When a bid is exchanged with a neighbouring system, the bid is paid the bid price, but it does not set the local imbalance price anymore
- It could therefore happen that the resulting local imbalance price is lower than the price of the bid exchanged
- In such a situation, the bid provider has no incentive to actually deliver as the imbalance price for non-delivery is smaller than the price paid

⇒When exchanging bids, the integrity of the balancing mechanisms must be kept.

- Incentives to avoid imbalance
- Incentive to participate in the regulation power market
- Incentive to delver when activated

Example of a TSO mandate issue

- In the German regulating power market all operationally required reserves are contracted and the contracts are paid by the German consumers
- The German TSOs are therefore contractually bound to only activate the contracted reserves for German imbalances

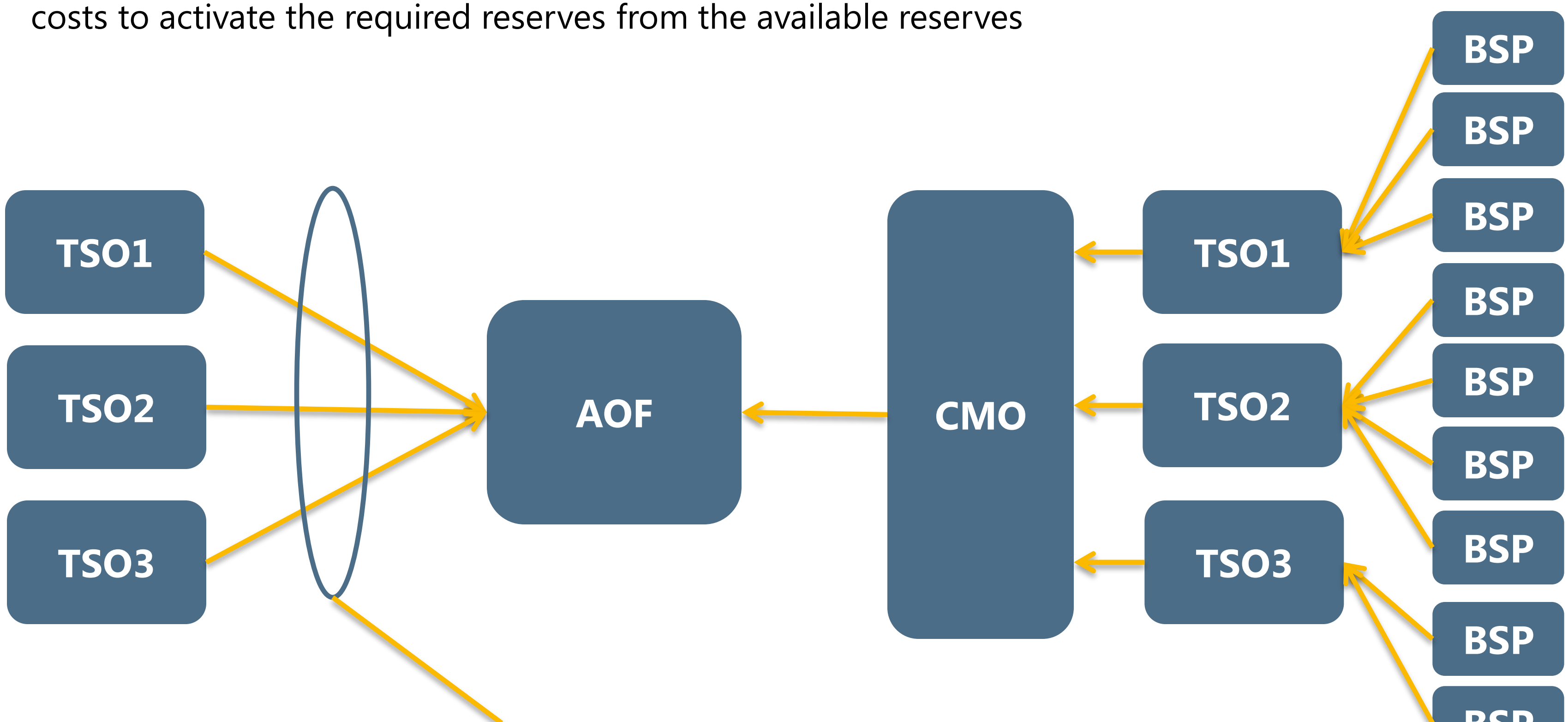
Other examples of potential TSO mandate issues

- The French TSO is mandated to pro-actively make transactions with market parties during market opening to prevent sytem imbalances
- German TSOs in their role of RES agents make transactions on the German intraday market to reduce RES imbalances
- Other TSOs are strictly forbidden to trade outside the regulating power market

- Should TSOs acting during market opening for the sake of preventing system imbalances be subject to the same market rules as any other market party?
  - Be balance responsible for the transactions made
  - Be charged an imbalance price for any imbalance between the transactions made and the realtime imbalance without a renumeration through the tariffs?
  - In order to avoid market distortions?

Activation optimization function

- The activation optimization function is at the hart of the sharing of reserves
  - It combines all needs for reserve activation from the TSOs and makes an optimal decision at least costs to activate the required reserves from the available reserves

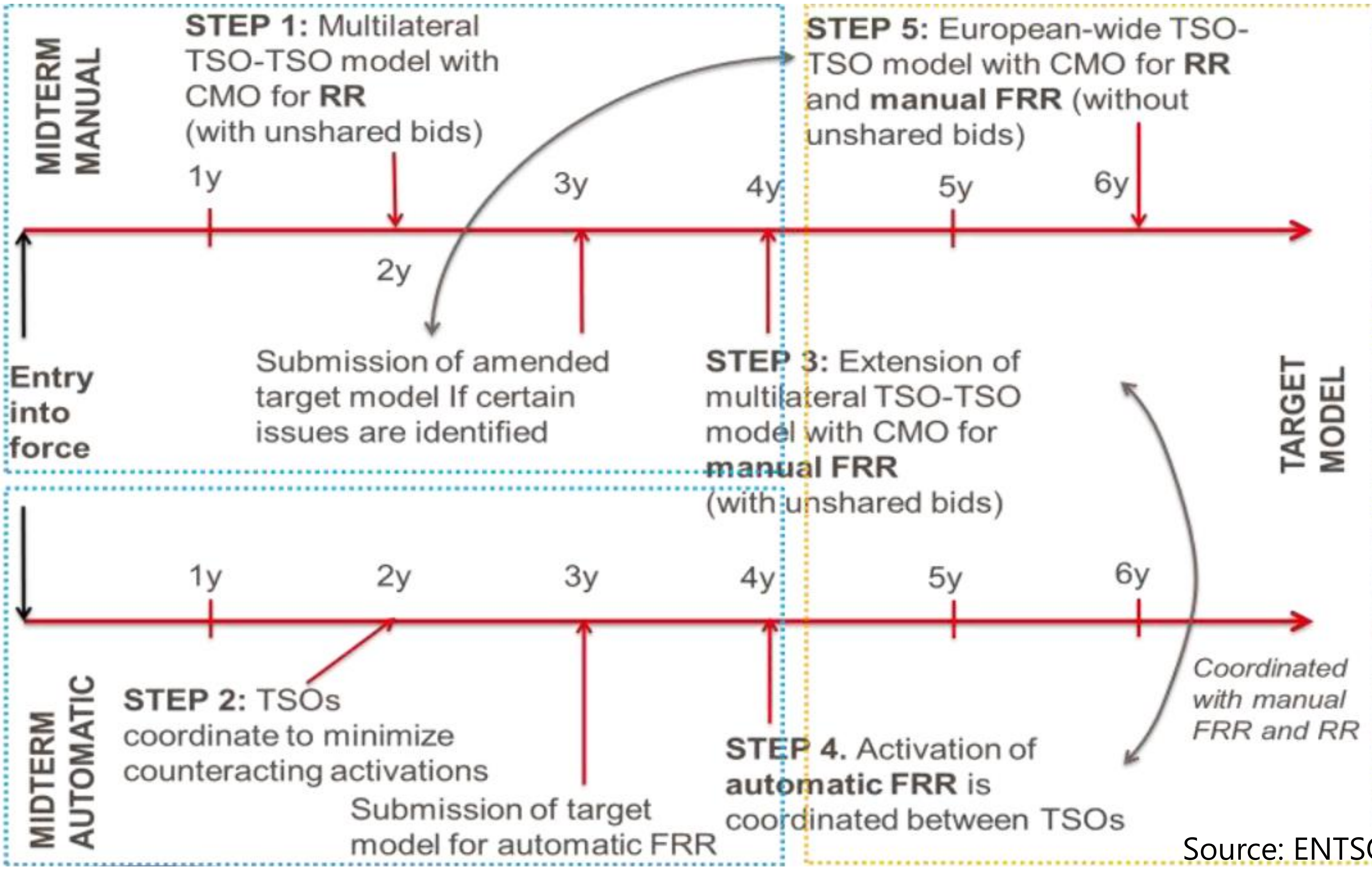


TSO competition for the cheapest bid?
Pro-active TSO mandate versus reactive mandate?

Coming to an integrated European Balancing Market

- Increasing complexity
  - Exchange of balancing services and products easier than sharing reserves
    - No common procedures necessary
  - Integration most challenging for the most complex products which are also the least harmonized in the following order:
    - FCR, FRR-A, FRR-M, RR
  - Activation optimization function becomes more complex when more products are shared over a wider geographical range

ENTSO-E roadmap for balancing market integration



Source: ENTSO-E

Interactive session:
How would the future European integrated balancing system look?

- In terms of standard products?
  - For FCR
  - For FRR-A
  - For FRR-M
  - For RR
- In terms of TSO roles? Are different roles compatible with the integrated market?
- In terms of interaction with intraday markets?
  - Should TSOs keep away from activating RR? If not, what should be the criterion to end RR activation?
  - Common shared order books?
  - Will the PXs become the service providers for balancing product order books and balancing capacity allocation for the TSOs? As they have become for day ahead and intraday capacity allocation?
- In terms of efficiency gain:
  - How does a parallel TSO role model compare with a sequential model in the long run?
  - Will more freedom to the market result in a more or in a less efficient balancing system

Questions?

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Finally: Will capacity mechanisms influence the balancing market?

- Are they needed?
  - Has all potential of the energy-only market been used?
  - How about demand-side response?
  - How about storage?
  - How about the increased market integration?
  - How about proper balancing incentives?
  - How about proper regulating power market participation incentives?

➔ Proper price signals will trigger market solutions, if given sufficient time

➔ Look for an international solution rather than a national one

- Alternatives
  - Security of Supply contracts: capacity obligations + reliability options
  - Strategic reserves

➔ investment risk is replaced by regulatory risk

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Capacity obligations with reliability options

Capacity obligations

- Generators selling capacity in a capacity auction have to ensure physical capacity.
- Generators receive capacity payment

Reliability options

- When the spot market price for electricity exceeds the exercise price, the providers of capacity are obliged to pay the difference between the spot market price and the exercise price to the central coordination agency.
- Example: spot price: 250 €/MWh, exercise price: 200 €/MWh, payment from option: 50 €/MWh

- Aimed to secure physical capacity

- Aimed to reduce risk of consumers
- Aimed to reduce incentives for market power abuse

Strategic reserves

- Some good design and operation principles
  - Design to increase investment incentives, not as an alternative to investments by the market
  - Do not interfere with forward market price settings
  - Do not apply a price for activation below any market price (including imbalance settlement price)
  - Last minute activation only, e.g. after all TSO balancing sources are exhausted, to give the market maximum opportunity to solve the problem itself
- Some bad design or operation principles
  - To mitigate peak forward prices (this reduces the investment incentives)
  - Premature activation, already before final market gate closure
- But:
  - Keeping strategic reserves operational, if not regularly used, is expensive
  - Difficult to resist early activation in cases of extreme market prices
  - …
- A good concept for strategic reserves is not straightforward !! There are many pitfalls and caviats