ELEC0018-1 Energy Markets

Lecture 6: Network Security

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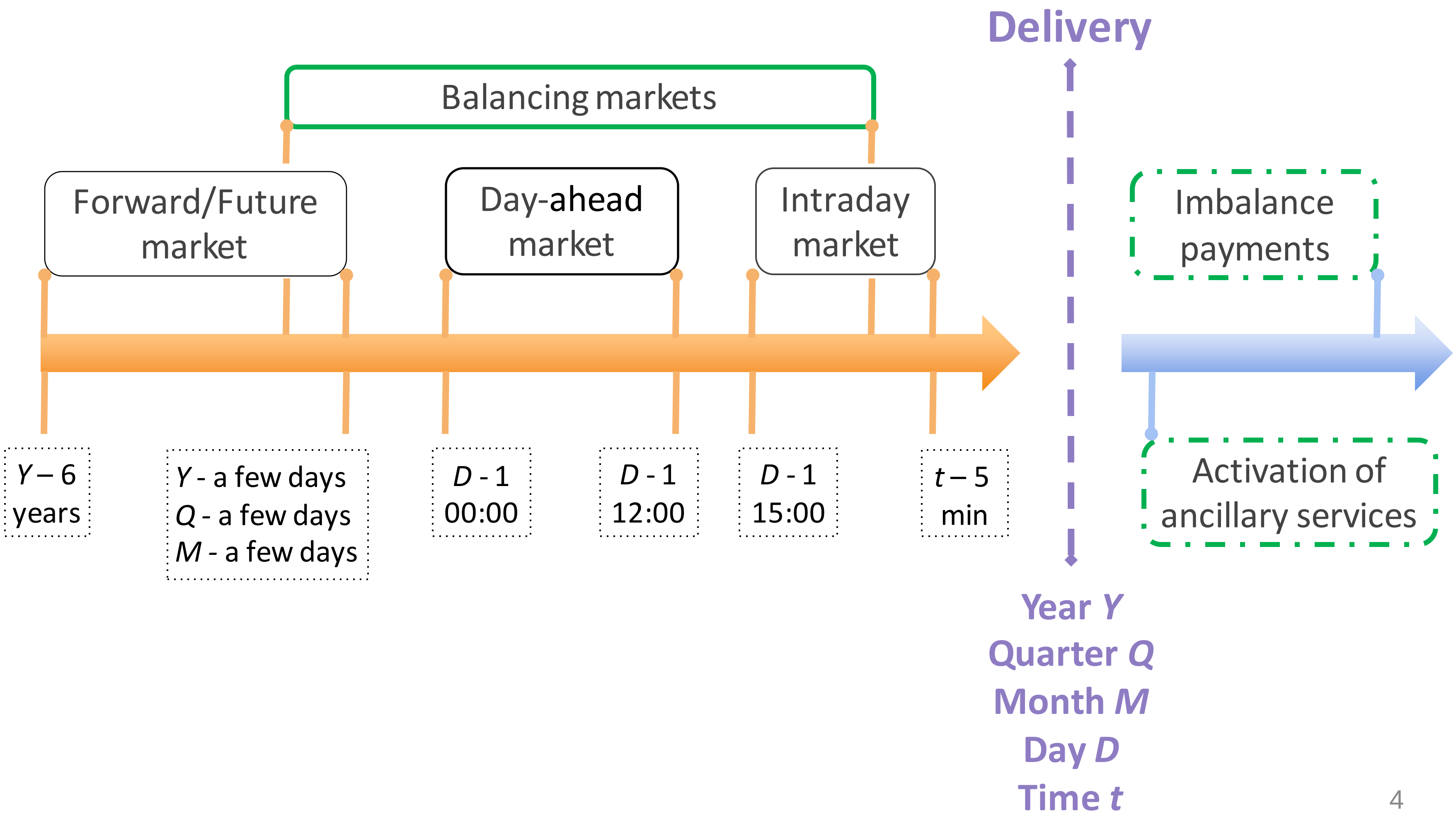
The question of the day

How to make sure that demand is always satisfied ?

Menu for today

1. Potential risks for the power system security
2. Ancillary services
3. Future system security

Reminder



Delivery
Balancing markets
Forward/Future market
Day-ahead market
Intraday market
Imbalance payments
Activation of ancillary services
Y – 6 years
Y - a few days
Q - a few days
M - a few days
D - 1 00:00
D - 1 12:00
D - 1 15:00
t – 5 min
Year Y
Quarter Q
Month M
Day D
Time t

From financial market to physical operation

Forward/future, day-ahead and intra-day markets are **financial** markets!

1. These are only transactions - No one is “forced” to generate or consume…
2. Both market participants and **system operator** are informed about market clearing outcomes (price and volumes for each market time unit)
3. In the European set-up, the market participants will then self-dispatch, i.e., determine themselves how they will generate or consume depending on volumes and prices

However, **imbalances may still arise** (i.e. amount contracted by a party to buy or sell **different** from the amount that it needs or can produce)

⇒ Managed markets are essential for balancing the load and generation and should **supersede** the open energy market (where most of the trading would occur) as time of delivery approaches.

ISO is given the responsibility to maintain the system balance.

Network security problems

What kind of security problems are we speaking of ?

Needs classified according to three different issues:

1. Balancing issues
2. Network issues
3. System restoration

Classification not perfect. Interactions for example between balancing and network issues.

Ancillary services needed for addressing every of these needs. The services are provided by the generators and the loads.

Source: [Kirschen]

Balancing issues

Assumption: all loads and generators connected to the same bus bar.

If too much generation, excess of energy stored by the generators under the form of kinetic energy ⇒ increase of the frequency.
If not enough generation, generators release kinetic energy ⇒ decrease of the frequency.

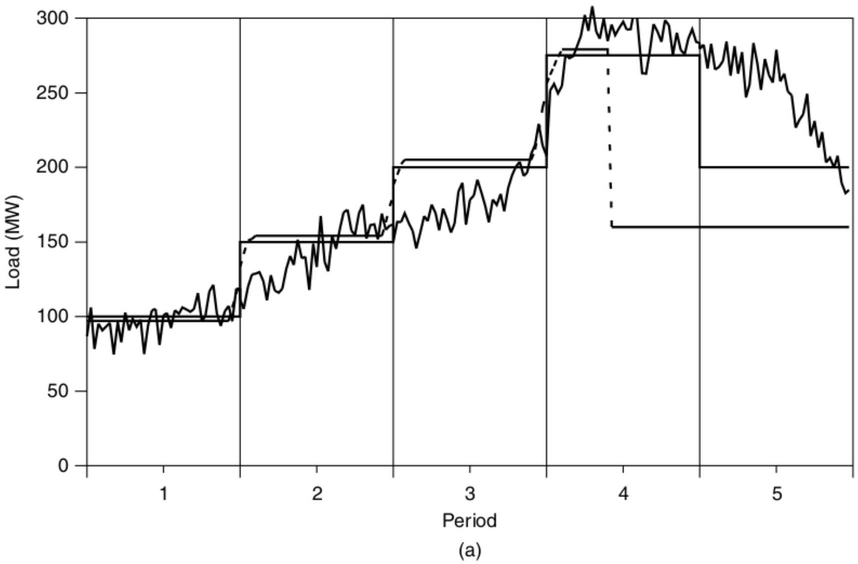
Systems with small inertia more vulnerable to frequency deviations.

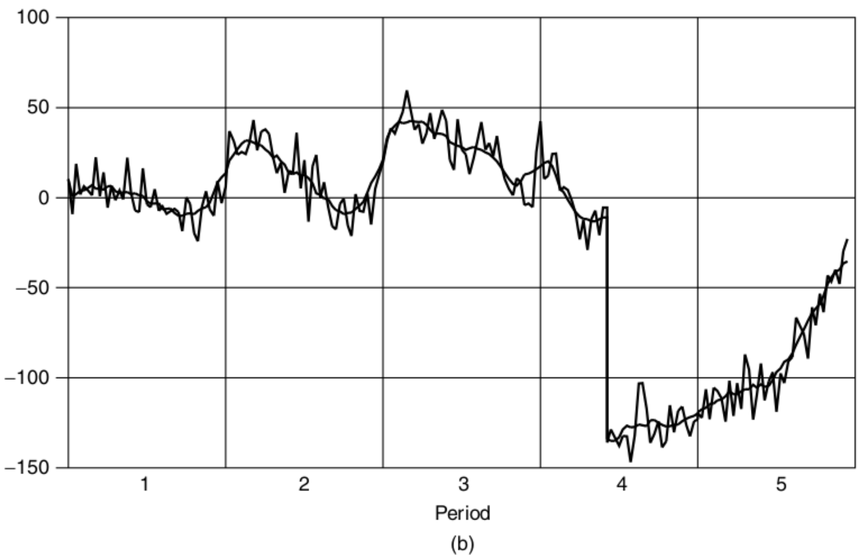
Large frequency deviations ⇒ overspeed or underspeed protection systems of generators activated ⇒ increase of the frequency deviations ⇒ . . . ⇒ System collapse.

General philosophy for handling balancing issues: try always to keep the frequency as close as possible to its nominal value.

Source: [Kirschen]

Balancing issues





(a) Load and generation fluctuations

(b) Resulting imbalances

Source: [Kirschen]

Imbalances between load and generation have three different components with three different time signatures:

1. rapid random fluctuations,
2. slower cyclical fluctuations, and
3. occasional large deficits.

System operator can treat them separately and can tailor the different ancillary services it needs to cope with a specific component of the total imbalance.

Regulation service: able to handle rapid fluctuations in loads and small unintended changes in generation. Provided by units that can rapidly increase or decrease their output.

Load-following service: able to handle slower fluctuations, in particular intraperiod changes that the market does not consider. Both services require more or less continuous actions from the generators providing these services.

Source: [Kirschen]

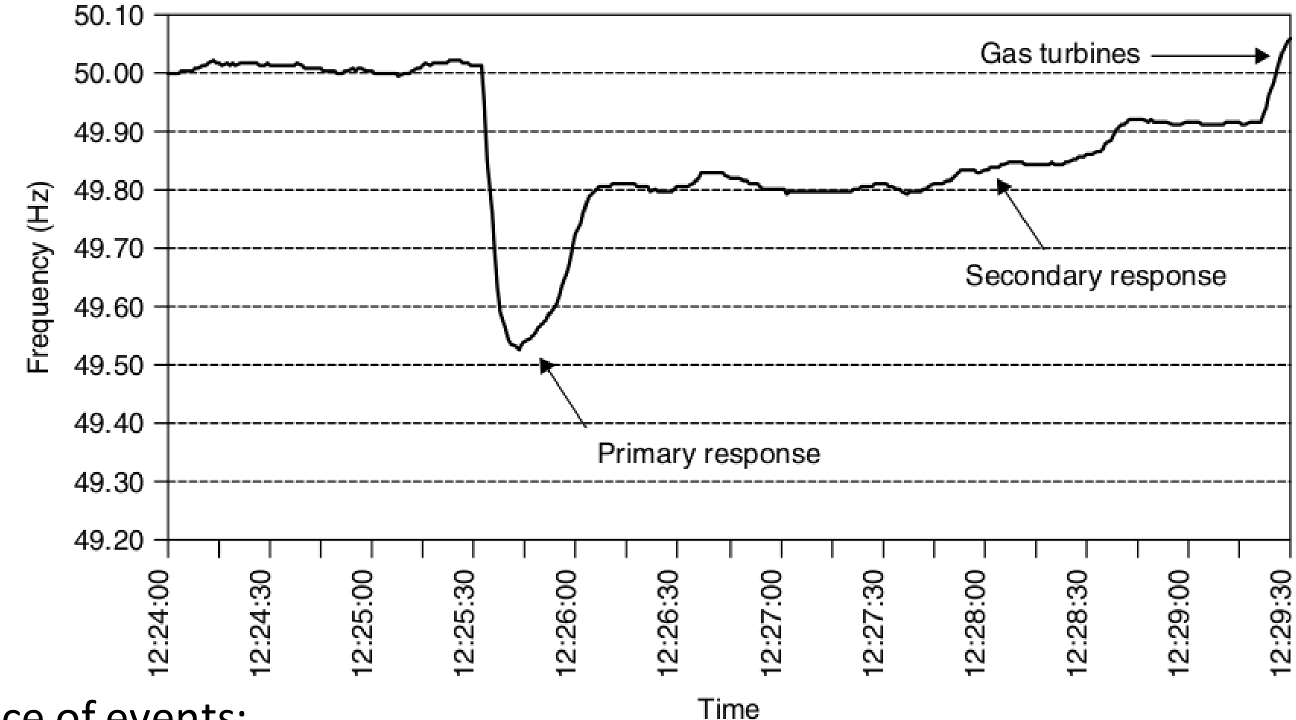
Reserve services: designed to handle large and unpredictable power deficits that could threaten the stability of the system. Classified as correctives actions. Obtaining reserve services is however a preventive security action.

Spinning reserve: available very quickly.

Supplemental reserve service: may be provided by units which are not synchronized to the grid but can be brought on line quick.

Customers that agree to be disconnected can also offer a reserve service.

Source: [Kirschen]



Sequence of events:

a. 1220 MW of generation lost in Great Britain (65 GW of installed capacity)
b. primary response that must be fully available after 10s and sustained for a further 20s succeeds to arrest the frequency drop
c. secondary response that must be fully available 30s after the incident and must be sustainable for a further 30 min enters into action to bring back the system closer to its nominal frequency
d. gas turbines enter into action which produce the last increase of the frequency

Source: [Kirschen]

Network issues

As loads and generations vary, the flows in the branches and the voltages at the nodes of the network fluctuate. The operator must ensure that the system is always in a safe operating point:

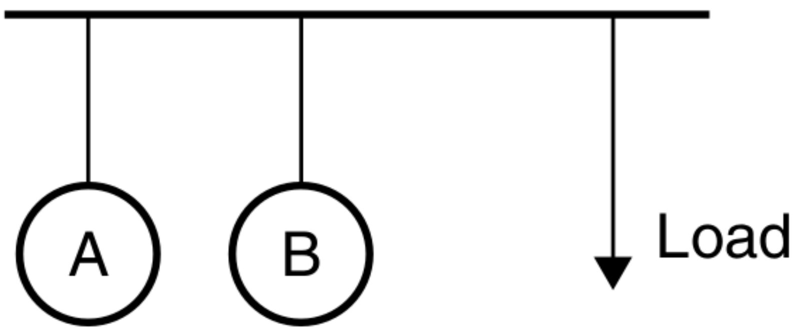
- no equipment overloaded,
- N-1 contingency analysis is OK (set of credible contingencies contains the outage of all system components taken separately)
- ...

Destabilization can take different form: cascading failures, voltage collapse of the system, loss of synchronism phenomena, large undamped oscillations that may activate protection relays, etc.

Source: [Kirschen]

Illustration of the limitations a N – 1 security criterion places on operation

System with two generators having a capacity of 100 MW each connected to a load.



Maximum load that can be handled securely is 100 MW and not 200 MW !

Source: [Kirschen]

Preventive and corrective measures for security

There are two ways of addressing security.

Preventive measures: Designed to put the system in a state such that the occurrence of a credible disturbance does not cause it to become unstable.

Corrective measures: Taken in the aftermath of a disturbance so as to ”save” the system.

Previous illustration: a mix of preventive and corrective actions. You preventively limit the maximum load you can serve but in case of an outage of a generator you may correctively adjust the generating power of the other.

Source: [Kirschen]

Preventive actions

If the state of the system is such that a credible contingency would trigger an instability, operators must take preventive actions.

Low or negligible cost preventive actions: adjusting the transformer taps, changing the topology of the system, changing the voltage set points of generators, rerouting power using phase-shifting transformers, etc.

High-cost preventive actions: As the loading of the system increases, there comes a point where security can only be ensured by placing limitations on the generation patterns. These limitations carry a very significant cost.

Lot of computation needed for selecting the best actions, especially when complex instability phenomena are considered.

Source: [Kirschen]

Voltage control and reactive support services

Several reactive resources and voltage control devices (capacitors, reactors, tap-changing transformers, etc.) are typically under the direct control of the operator. However generating units provide the best way to control voltage:

⇒ a voltage control service (also called reactive power support service) needs to be defined to specify the conditions under which the system operator can make use of the resources owned by the generating companies.

Specification of the conditions difficult : must consider the operation of the system under normal operation but also unpredictable outages.

Source: [Kirschen]

Specifications for reactive support services: example

Type of specifications:

1. keep the voltage at the generator bus node within a certain interval when normal operating conditions (typically, $0.95 \text{ p.u.} \leq V \leq 1.05 \text{ p.u.}$) (reasons: facilitate voltage regulation at the distribution level, high voltages under normal makes the system more robust to disturbances, etc)

2. Capability to provide reactive power reserve in case of emergency.

Source: [Kirschen]

Stability services

System operators may also need to obtain other network security services from generators such as for example:

Intertrip schemes: in the event of a fault, they automatically disconnect some generation and/or some load to maintain the stability of the system.

Power system stabilizers: adjust the output of generators to dampen oscillations that might develop in the network. Can increase the amount of power that can be transmitted in a line.

Source: [Kirschen]

System restoration

Disturbances may spiral out of control and the entire power system may collapse !

The system operator has the responsibility to restore the system as soon as possible.

But restarting large thermal plants requires a significant amount of power ... which is not available if the entire system has collapsed.

Some generators (e.g., hydro-plants, diesel generators) can however restart in an autonomous way.

The system operator must ensure that enough of these restoration resources are available. This ancillary service is usually called black-start capability.

Source: [Kirschen]

Ancillary services

Practical information

1. For ULiège (including Erasmus) students, the project is available on the website. Helmo students can also try doing it if they want.

2. For Helmo students, we need to fix a date for the exercise evaluation.

Game for today

1. 10 questions at different moments in the class
2. Questions can be on subjects seen on other days or that I just explained
3. Answer in less than 1 minute (conciseness)
4. Get 1 point for your team each time you answer well
5. Max 2 answers by person
6. The team with most points wins a price next class

Question 1

Cite the three types of issues that might occur in an electricity network

Question 2
Cite the three types of ancillary services

Obtaining ancillary services

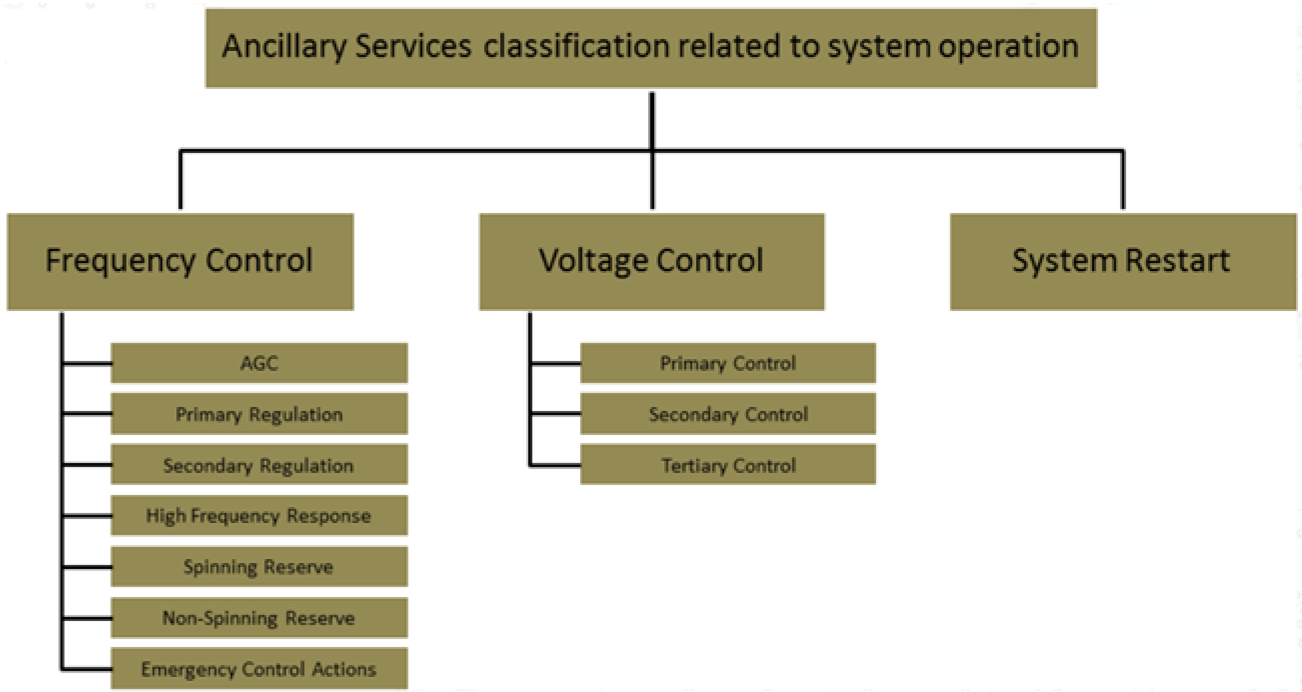
We have seen that power system operators need some resources to maintain the security of the system and that some of these resources must be obtained from other industry participants in the form of ancillary services.

These include:

- black start capability (the ability to restart a grid following a blackout);
- frequency response (to maintain system frequency with automatic and very fast responses);
- fast reserve (which can provide additional energy when needed);
- the provision of reactive power
- and various other services.

Source: [Kirschen], https://docstore.entsoe.eu/about-entso-e/market/balancing-and-ancillary-services-markets/Pages/default.aspx

Various types of ancillary services



Source: [Pinson]

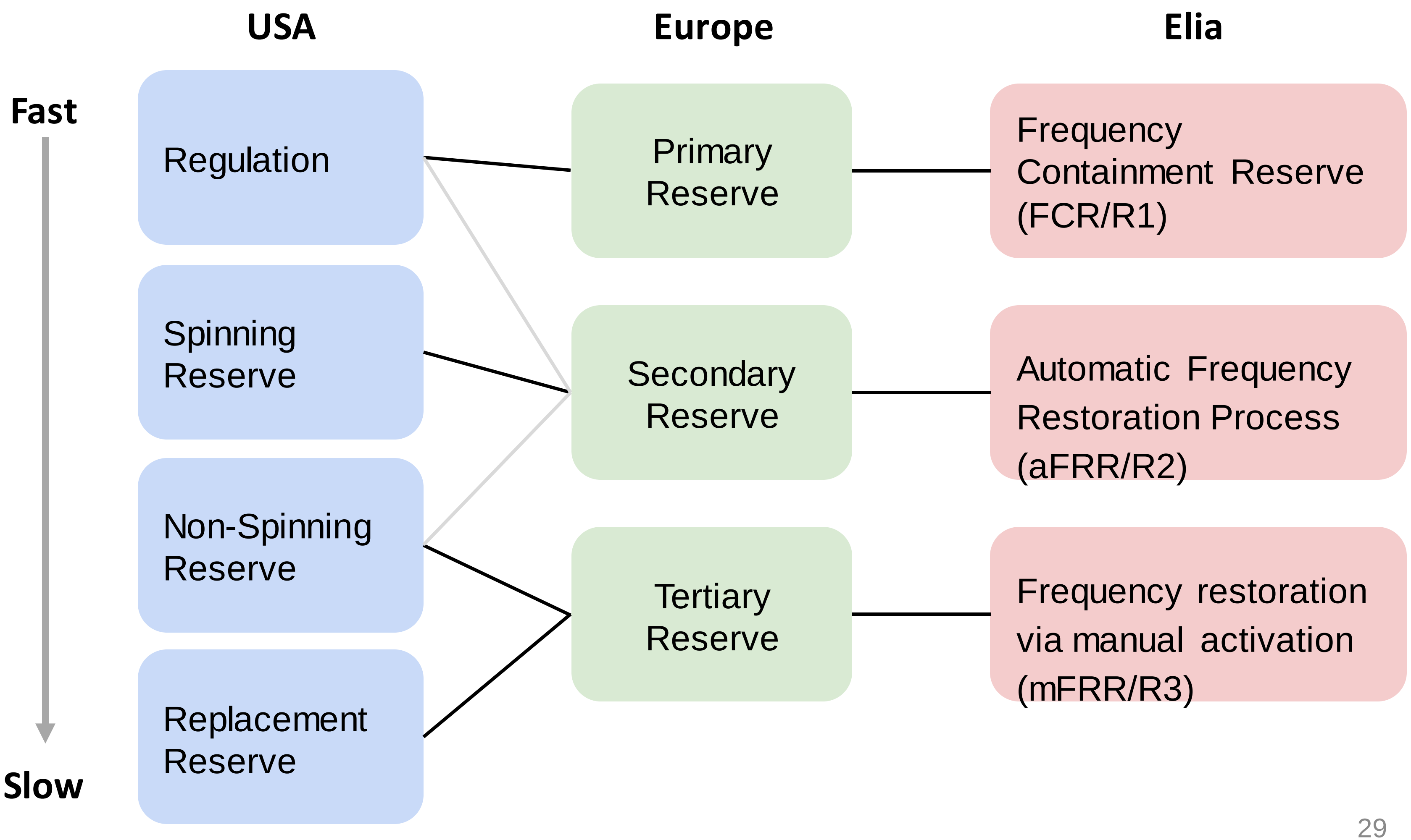
Voltage control

Primary : control of voltages at the buses of generators

Secondary : control for having a good overall voltage profile

Tertiary : minimisation of losses + considering security constraints

Frequency control
- Beware of naming conventions



Ancillary services – Reserves

Primary reserve:

- Automatically activated within 30 seconds
- Goal: stabilizing frequency by equilibrating generation and consumption

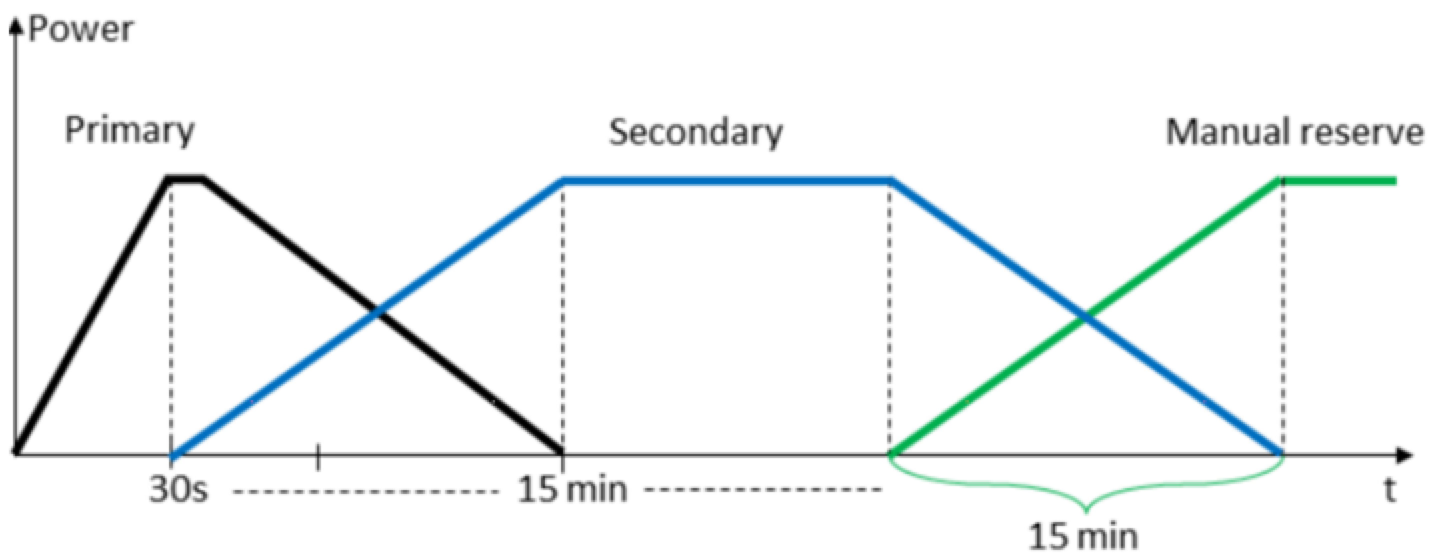
Secondary reserve:

- Automatically activated within 15 minutes
- Goal: get the power grid back to its target frequency

Tertiary reserve:

- Manually activated
- Goal: backup for the secondary reserve

Ancillary services – Reserves



Source: [Pinson]

Obtaining ancillary services

Let us examine two mechanisms for obtaining these ancillary services

1. Making the provision of some ancillary service compulsory.
2. Create a market for these ancillary services.

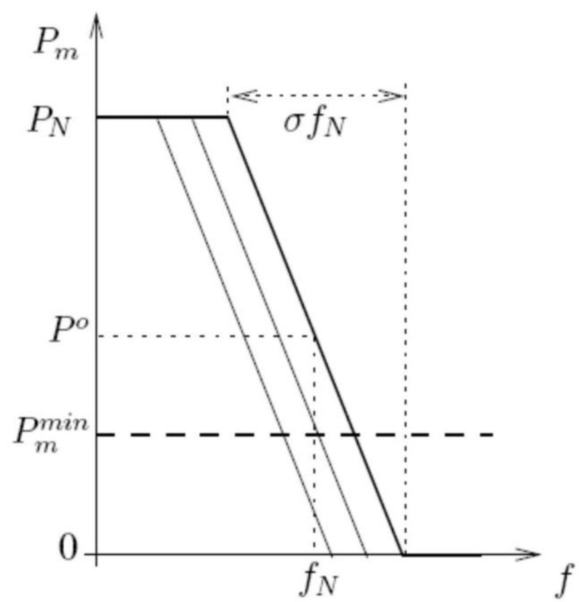
Choice of one mechanism to the other influenced by the type of ancillary service, the nature of the power system and historical circumstances.

Source: [Kirschen]

Compulsory provision of ancillary services

As a condition for being allowed to connect, a category of industry participants is required to provide a certain type of ancillary service. Example, generating units may be required to be:

- equipped with a 4 % droop coefficient (σ) to ensure that all units contribute equally to frequency regulation
- capable of operating with a power factor (P/S) ranging from 0.85 lead to 0.9 lag and be equipped with voltage regulators.



Source: [Kirschen]

The cons for compulsory provision

1. **Unnecessary investments**: not all generating units need to take part in frequency control, not all the units need to have power system stabilizers.
2. Does **no**t leave room for **technological improvements** or **commercial innovation** (e.g., you could using IT system provide all types of balancing services by modulating the load).
3. **Unpopular**. Providers may feel that they are forced to supply a service for which they are not paid (e.g., producing reactive reserves increases losses and the maximum amount of active power that can be produced)
4. Participants may be unable to provide services (e.g., nuclear units cannot change rapidly their power output). **Compulsion therefore not applicable for some services.**
5. **Inefficient use of resources**. For example, efficient units should not be forced to operate at part load so they can provide reserve.

Source: [Kirschen]

Markets for ancillary services

Instead of making the provision compulsory, the ISO can organise markets where it will buy ancillary services to other market participants. Different types of markets can coexist for exchanging different products.

Long-term contracts are preferred for services in which the amount needed does not change (or very little) with time such as: black-start capability, intertrip schemes, power-system stabilizers and frequency regulation.

Spot market needed for services in which the needs vary substantially over the course of the day and offers change because of the interactions with the energy market. Last part of the necessary reserve is often provided by a short-term market mechanism.

In Europe, those markets are based on two types of actors

1. Balance Responsible Parties (BRP)
2. Balance System Providers (BSP)

Balance Responsible Party (BRP)

'Balance Responsible Party' (BRP) in the electricity market is a market participant or its chosen representative **responsible for its imbalances**.

The BRP may be a producer, major customer, energy supplier or trader.

As a result, each BRP is responsible for a portfolio of **access points** and must develop and take all reasonable measures to maintain the balance between injections, offtakes and commercial power trades within their portfolio.

A list of Belgian BRPs is available at http://publications.elia.be/upload/List_Arp.html

Source: https://www.elia.be/en/electricity-market-and-system/role-of-brp

BRP - Daily balance schedule

[Belgian case]

One day before the period in question, the BRP must submit to Elia a daily balance schedule for their portfolio for day D, which consists of:

- Expected injections and offtakes at each access point;
- Commercial power trades, i.e. purchases and sales, with other BRPs and/or related to imports and exports on the borders.

In Belgium, the daily balance schedule must be balanced on a **quarter-hourly basis**: the sum of injections and purchases must equal the sum of offtakes and sales.

To maintain balance at portfolio level, a BRP can use a hub or a power exchange to exchange energy with other BRPs for the following day (day-ahead) or for the same day (intraday).

BRP - Imbalance tariffs

[Belgian case]

Elia uses the ex-post measurement data of the access points and the commercial trade schedules to verify whether a BRP has remained balanced.

If a BRP incurs an imbalance on a quarter-hourly basis, the BRP is subject to the imbalance tariffs.

The imbalance tariff **incentivises the BRP to keep their portfolio balanced** or, in certain conditions, to help Elia keep the grid secure and reliable.

Question 3
What is a BRP?

BSP - Balance Service Providers

To correct the imbalances created by BRPs

⇒ the ISO organises balancing markets

These markets offer flexibility:

- in the form of **ancillary services**
- provided by **Balance Service Providers** or BSPs

Note about demand-side provision of ancillary services

Historically, generating units provided all the ancillary services.

In a competitive environment, the demand-side should also be able to offer these services.

All the balancing issues could be tackled in principle by the demand-side.

Demand-side could also in principle help to tackle other instability issues such as voltage instability, loss of synchronism phenomena, damping of oscillations, etc.

HUGE OPPORTUNITIES FOR NEW BUSINESSES!

Source: [Kirschen]

Buying ancillary services

System operator responsible for buying the ancillary services on behalf of the users of the system through a market mechanism.

System operator users pays the providers of these services and recover costs from users.

Needs to buy the optimal amount of services and pays the right price for it.

Users need to pay a fair share of the costs.

Source: [Kirschen]

Quantifying the needs

Cost/benefit analysis: Level of needs at the point where the marginal cost of providing more security is equal to the marginal value of security.

Marginal cost of security: how much does it cost to increase reliability of the system. Can be defined for example using probabilistic models that for a given level a security give the amount of load that cannot be served during one year.

Marginal value of security: what is the value of an increase of security to the customers.

Question: If the cost is passed on user, what is the incentive for the operator to buy the optimal amount of ancillary services and, to a least extend, at the minimal cost ?

Source: [Kirschen]

What for and how is the system operator paying ?

Depending on the reserve, the ISO might be paying for:

Capacity and/or energy

For example, primary reserves are ‘energy-neutral services’ in the sense that the BSP are only paid for the capacity they provide.

Based on the acquired reserves, the ISO will set an **imbalance price** or **imbalance tariff**.

⇒ BRP in imbalance need to pay their imbalance times this tariff.

Allocating the costs

Not all the consumers value system security equally. Example: cost of service interruption greater for a semiconductor factory than a residential customer ⇒ Customers should be able to pay for a desirable level a reliability. But selling customized-reliability too difficult to achieve in practice.

Requirement for load following and regulation services depend on the customers. Typically, industrial customers need more regulation ⇒ cost should be allocated according to the type of the load to avoid to have a cluster of customers that subsidizes another.

In practice, since all users get the same level of security, cost of the ancillary services is shared among all users of some measure of their use of the system, typically the energy consumed or produced.

Source: [Kirschen]

Future system security

Preparing for the future

Ancillary services are useful to ensure the security of the system on the short- to mid-term.

However, they do not ensure that sufficient capacity will be available in the future.

Need the right investments (in amount and type):

- In transport
- In generation
- In storage (possibly)
- In demand-side management (to alleviate investments in the other categories)

The future of the network

As explained in previous lessons, investments in network are financed through taxes and/or via congestion surplus.

Investments decisions are made by the regional monopolies or by governmental agencies (both can be the same).

In Europe, decisions for transmission investment are made at the European level through a cost-benefit analysis explained in the Ten-Year Network Development Plans (TYNDP) compiled by ENTSO-E. See last report here: https://tyndp.entsoe.eu/.

The future of generation

Energy markets should be designed to ensure that sufficient investments are made in capacity to cover future demand.

Also, these investments often need to match with the current political agenda.
E.g.

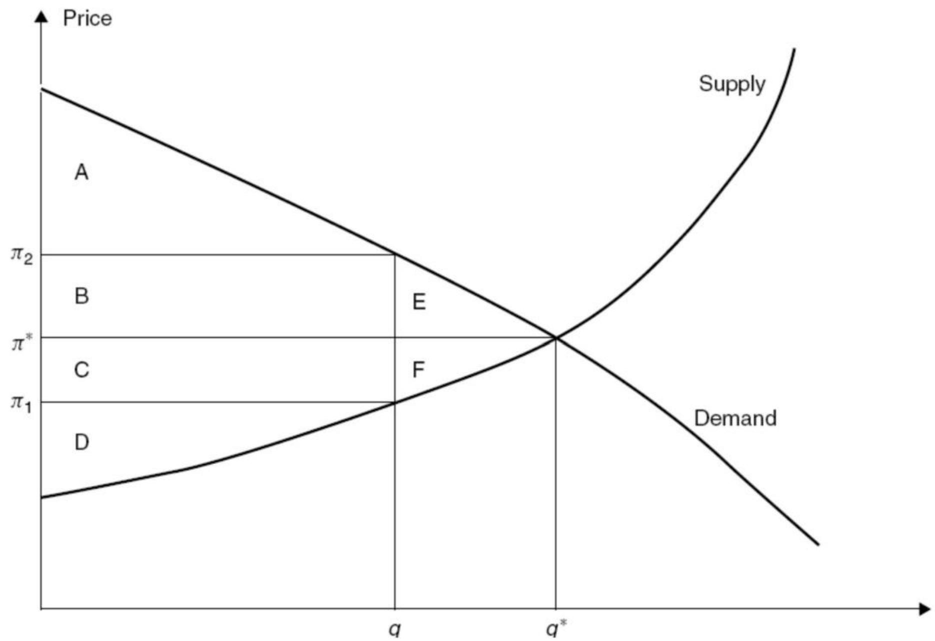
- Energetic independence in the 1970s – large nuclear investments
- The current energy transition – major investments in new renewables

These two objectives might not align. Need for regulation but regulation might interfere with the proper workings of the market and require complementary mechanisms.

Three examples: price caps, renewable support, CRM

Impact of price caps

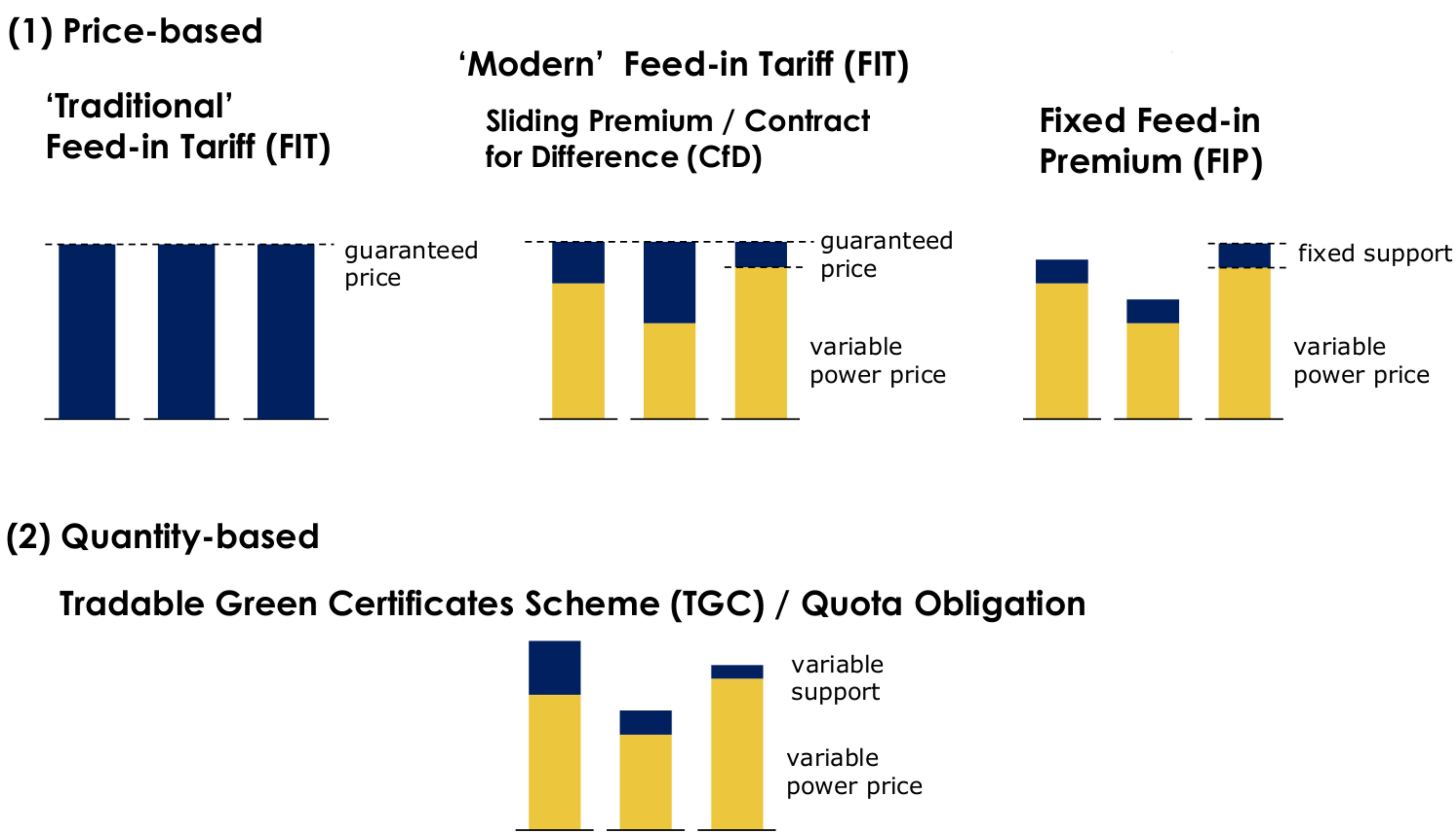
Enforcing a maximum price or price cap leads to a deadweight loss, i.e. a drop in social welfare.



In this example, the social welfare drops from ABCDEF to BCD when setting a price cap at π_2.

Source: [Kirschen]

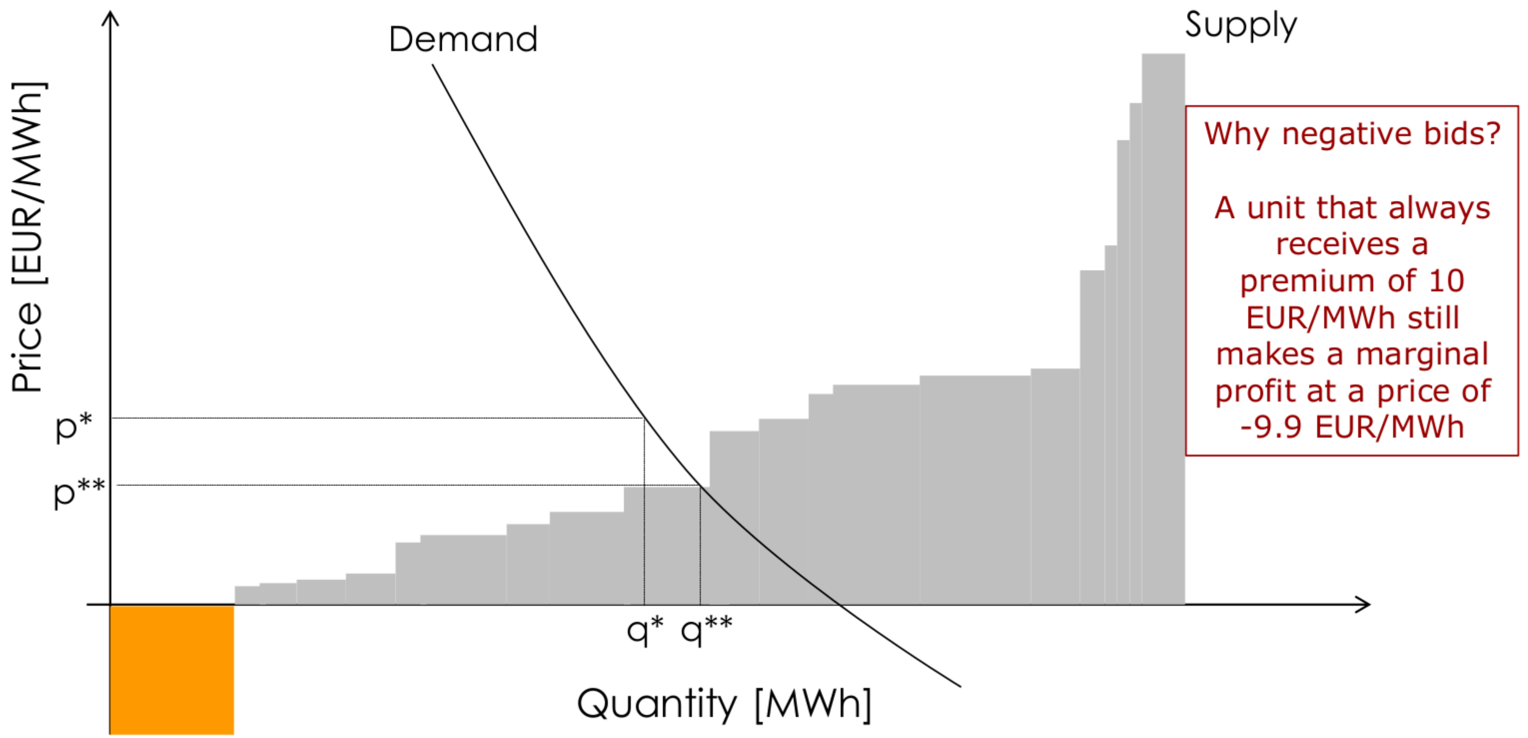
Generation-based RES support



Source: [Pinson]

How would a supported wind park bid into the spot market ?

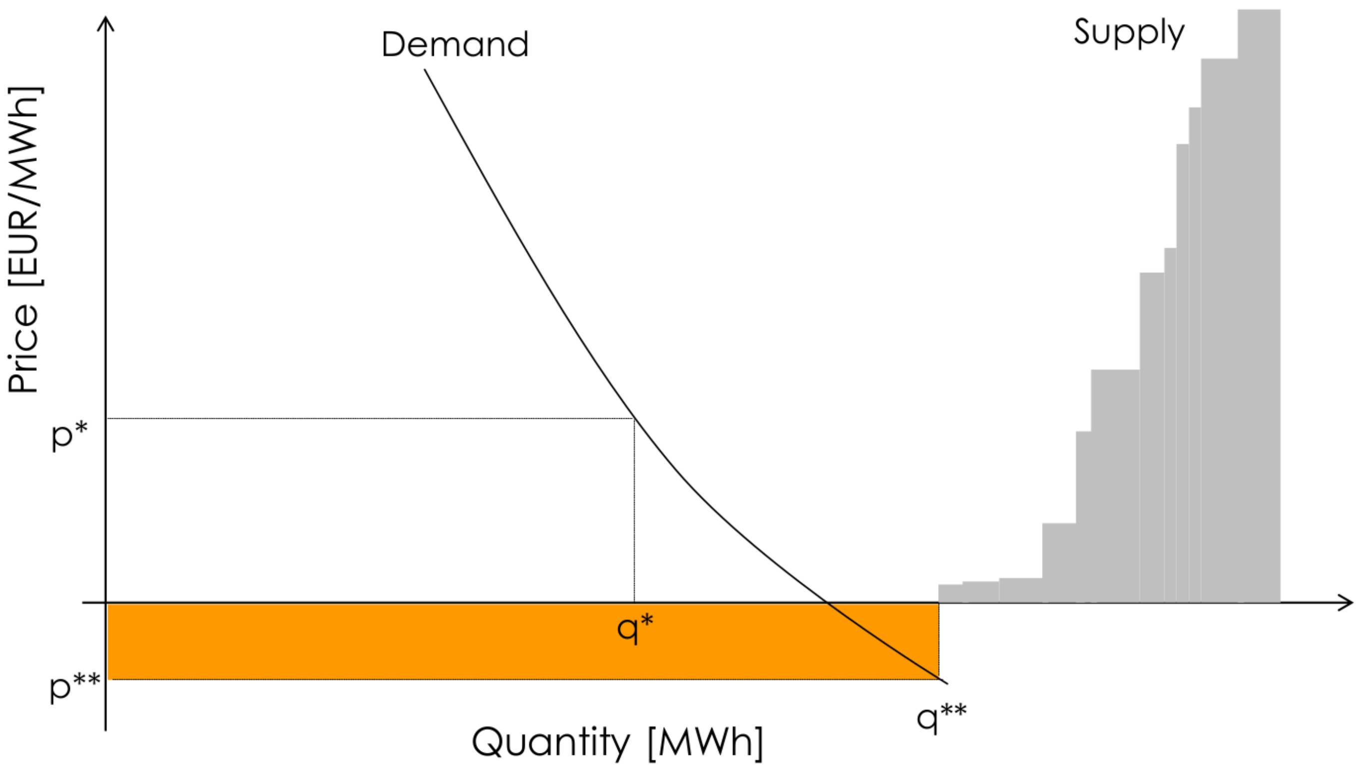
'Traditional' Feed-in tariff: *No bidding – production at all prices*
'Fixed' Feed-in premium: *Bidding at minus the premium*
'Sliding premium' Feed-in tariff: *Bidding at the smallest possible negative value*



Source: [Pinson]

And what is the effect on market price ?

As soon as supported units become price setters (= at high market shares), we need adjustments of support scheme design



Source: [Pinson]

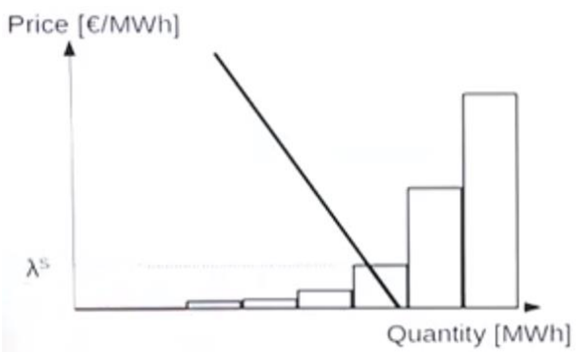
Question 4
Explain two types of RES support

How to deal with negative prices?

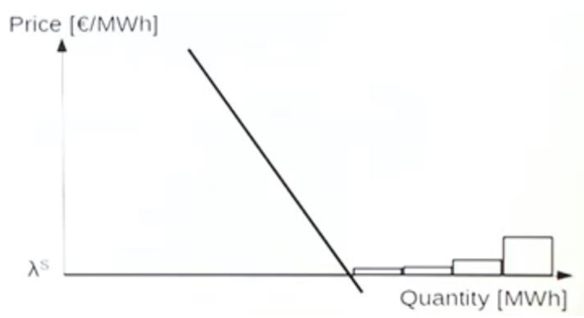
A possibility is to state that if clearing prices become negative, market participants lose their support (CfD or FIP).

In both cases, the optimal strategy is then to offer at 0 €/MWh.

Effect if few renewable producers



If quite many of them



Clearing prices decrease when the number of renewable producers increase but they never become negative.

Source: [Pinson]

A rising need for reserve

Fluctuations of renewables and forecast errors lead to:

1. increase need for balancing reserves
2. impacts the system costs

Increasing need for fast-ramping controllable generation unit, e.g. CCGT.

Current market mechanisms might not be sufficient to support investments in these units if prices are not high enough for sufficiently long times.

Need support mechanisms for those technologies too, e.g. Capacity Remuneration Mechanism (CRM).

Source: [Pinson]