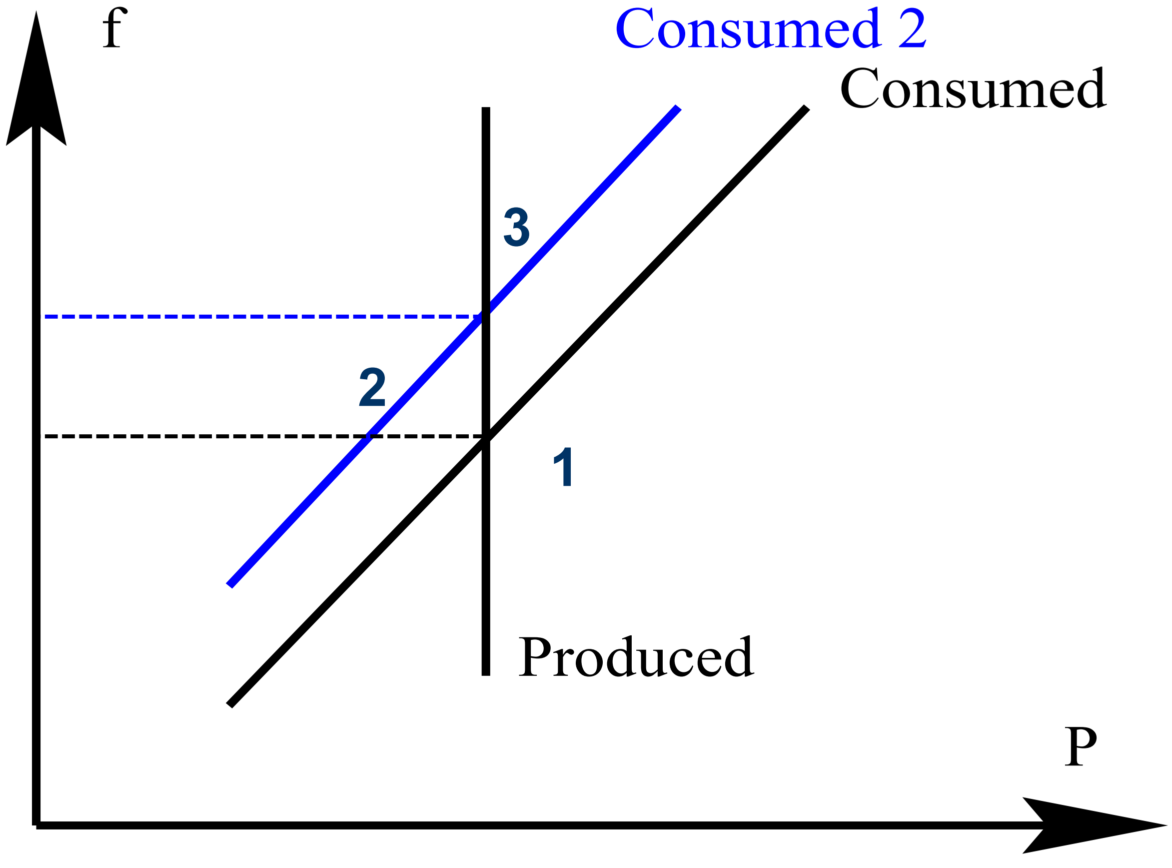
Why frequency control?

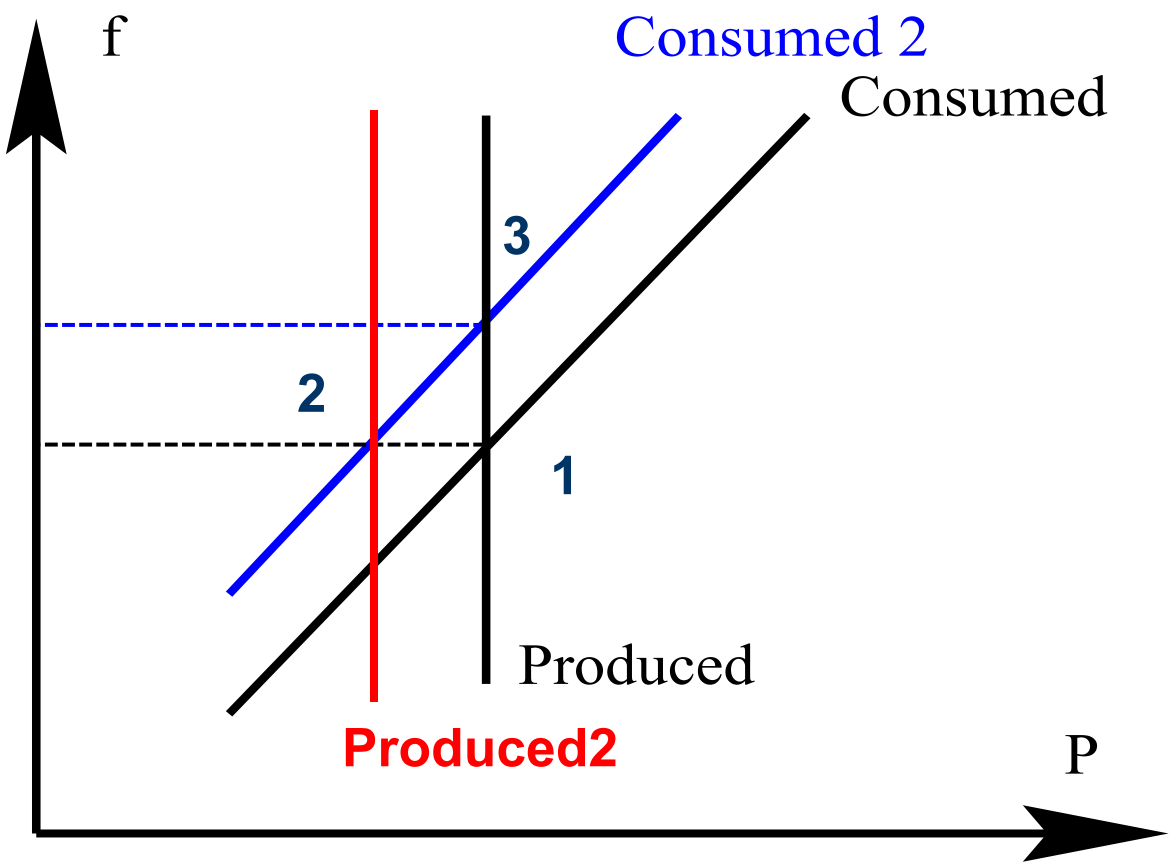
- Uncontrolled power variations affect machine speed
- Frequency has to remain between very strict limits



1. **Start**
2. **P_consumed2 < P_consumed1**
3. **P_produced > P_consumed ➔ acceleration**

Why frequency control?

- Uncontrolled power variations affect machine speed
- Frequency has to remain between very strict limits



1. Start
2. P_consumed2 < P_consumed1
3. P_produced > P_consumed ➔ acceleration (delta f)
4. Production has to be reduced (control action)

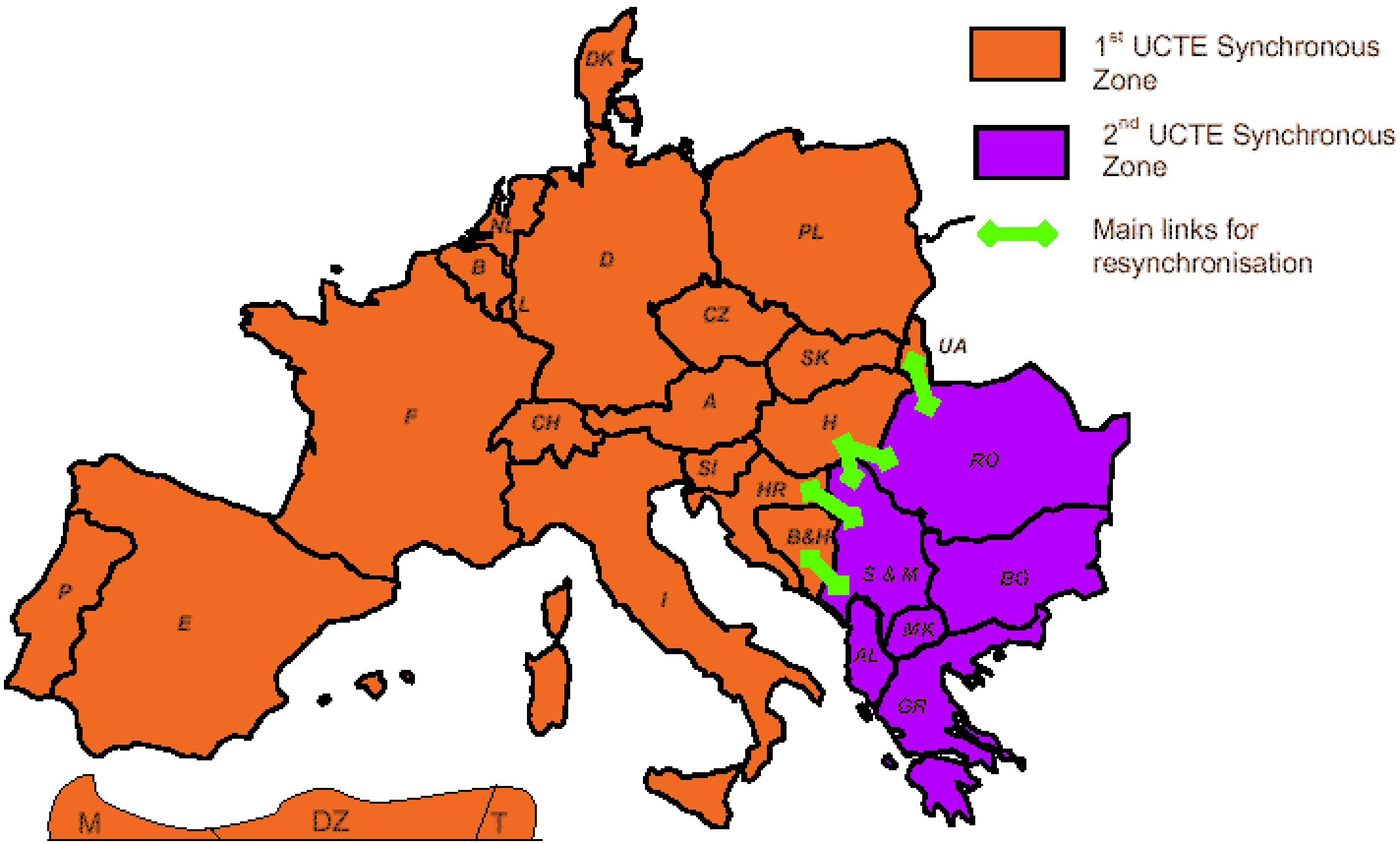
Frequency control
Different control actions

- ***4 Phases***
  - ***Primary control***
    - *maintains the balance between generation and demand in the network using turbine speed governors. (tens of seconds)*
  - ***Secondary control***
    - *centralised automatic function to regulate the generation in a control area based on secondary control reserves in order to*

      • maintain its interchange power flow at the control program with all other control areas

      • restore the frequency in case of a frequency deviation originating from the control area to its set value in order to free the capacity engaged by the primary control. (15 min)
  - ***Tertiary control***
    - *any (automatic or) manual change in the working points of generators (mainly by re-scheduling), in order to restore an adequate secondary control reserve at the right time. (after 15 min)*
  - ***Time control***
    - *integral control of the system time regarding UTC time, days*
- ***Internationally controlled (UCTE, Nordel, a nd others)***
- ***Operation handbook: http://www.ucte.org/publications/ophandbook/***

UCTE



1st UCTE Synchronous Zone
2nd UCTE Synchronous Zone
Main links for resynchronisation
DK
NL
B
L
D
PL
CZ
SK
UA
A
H
RO
CH
F
SI
HR
B&H
S & M
BG
MK
AL
GR
I
P
E
M
DZ
T

Primary control
Grid characteristics

- Statism:

$$S_G = \frac{-\Delta f / fn}{\Delta P_G / P_{Gn}}$$

  - In %, typically 4 to 5 %
  - Highest droop = largest contribution

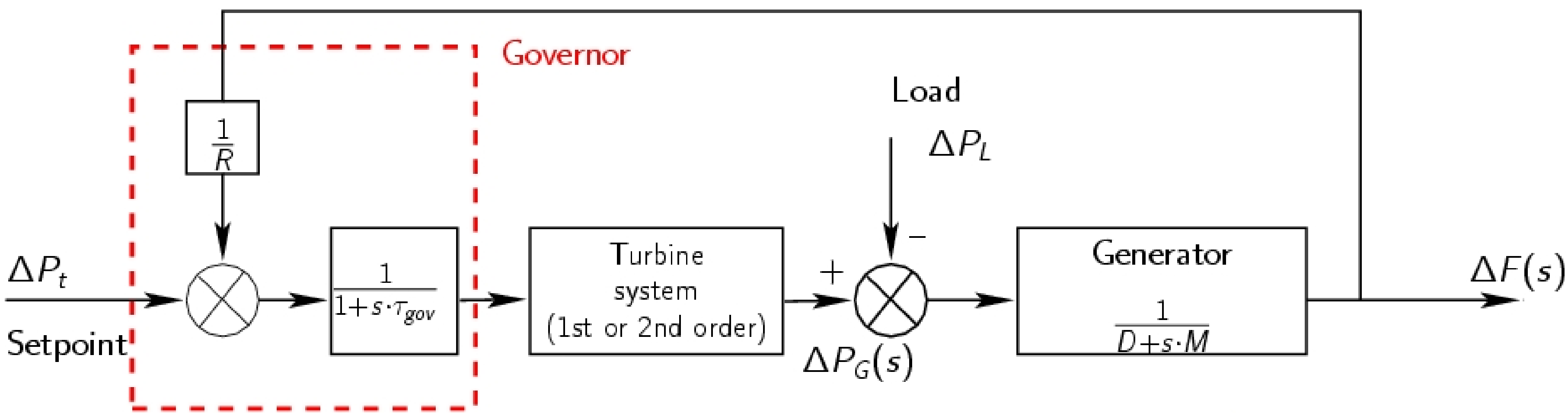
$$\lambda = -\frac{-\Delta P_{G^\circ}}{\Delta f}$$

- Network stiffness
  - Also called `Network power frequency characteristic'
  - Includes self regulating effect (D) and influence of the feedback control (K=1/R)

$$\lambda = \frac{1}{R} + D$$

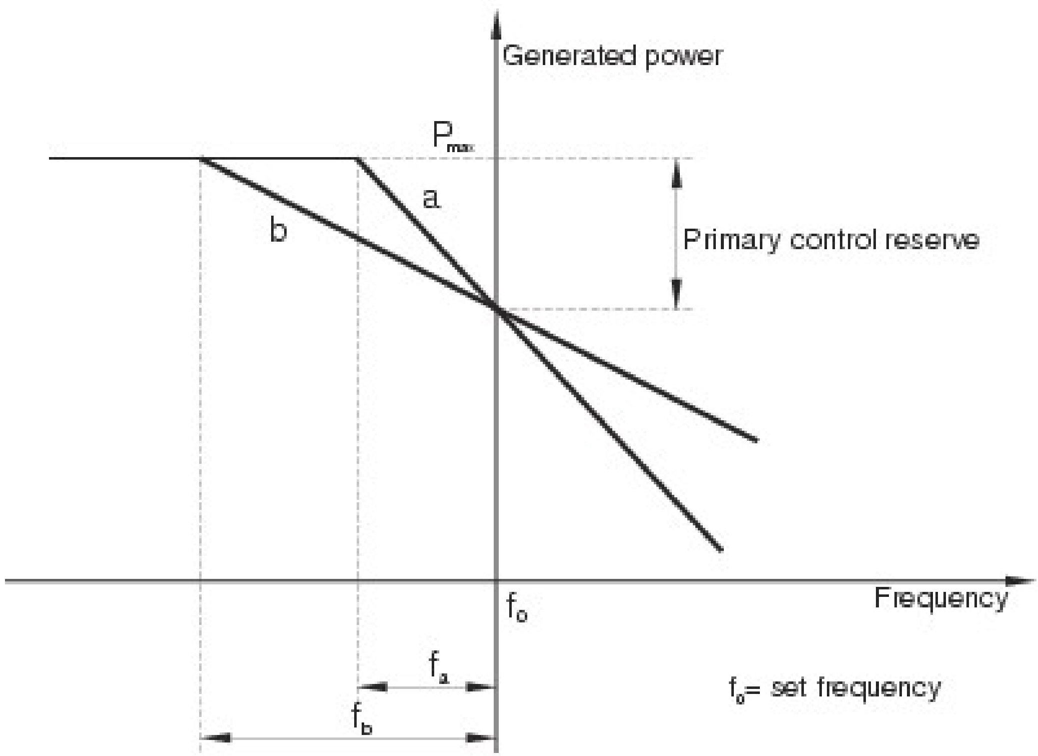
Primary control principle

- Balancing generation and demand in a synchronous zone
- Device is called `governor'
- Maximum allowed dynamic frequency deviation: 800 mHz
- Maximum allowed absolute frequency deviation: 200 mHz



Primary control principle

- Variations in the generating output of two generators
- Different droop
- Under equilibrium conditions
- Identical primary control reserves



Primary control Principle (II)

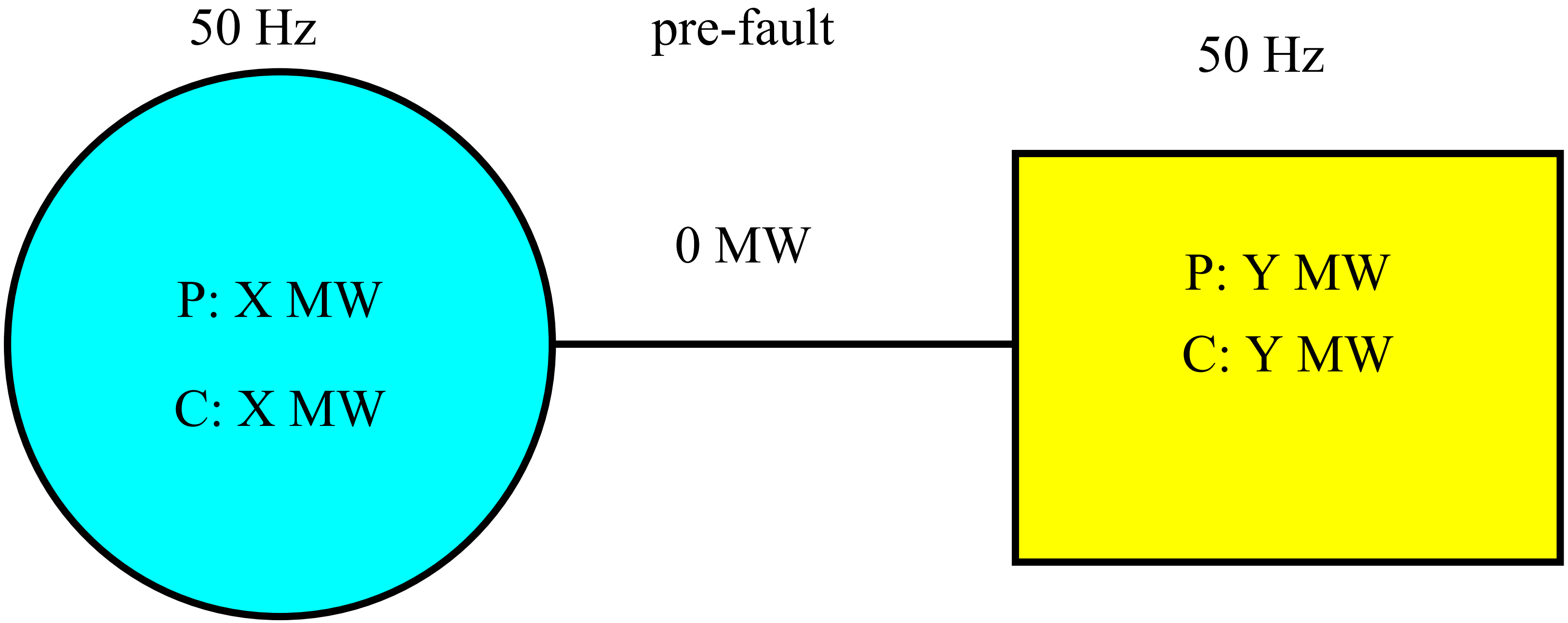
- When $\Delta f > 1Hz$, a part of the load is shed
- Basic principle: P-control feedback to counter power fluctuations
- Primary control uses spinning reserves
- **Each control area within the synchronous area (UCTE) has to maintain a certain reserve, so that the absolute frequency shift in case of a 3 GW power deviation remains below 200 mHz**
  - **3 GW are two of the largest units within UCTE**
- **If $\frac{\Delta f}{t}$ is too high ==> islanding**

Secondary control Definition/principle

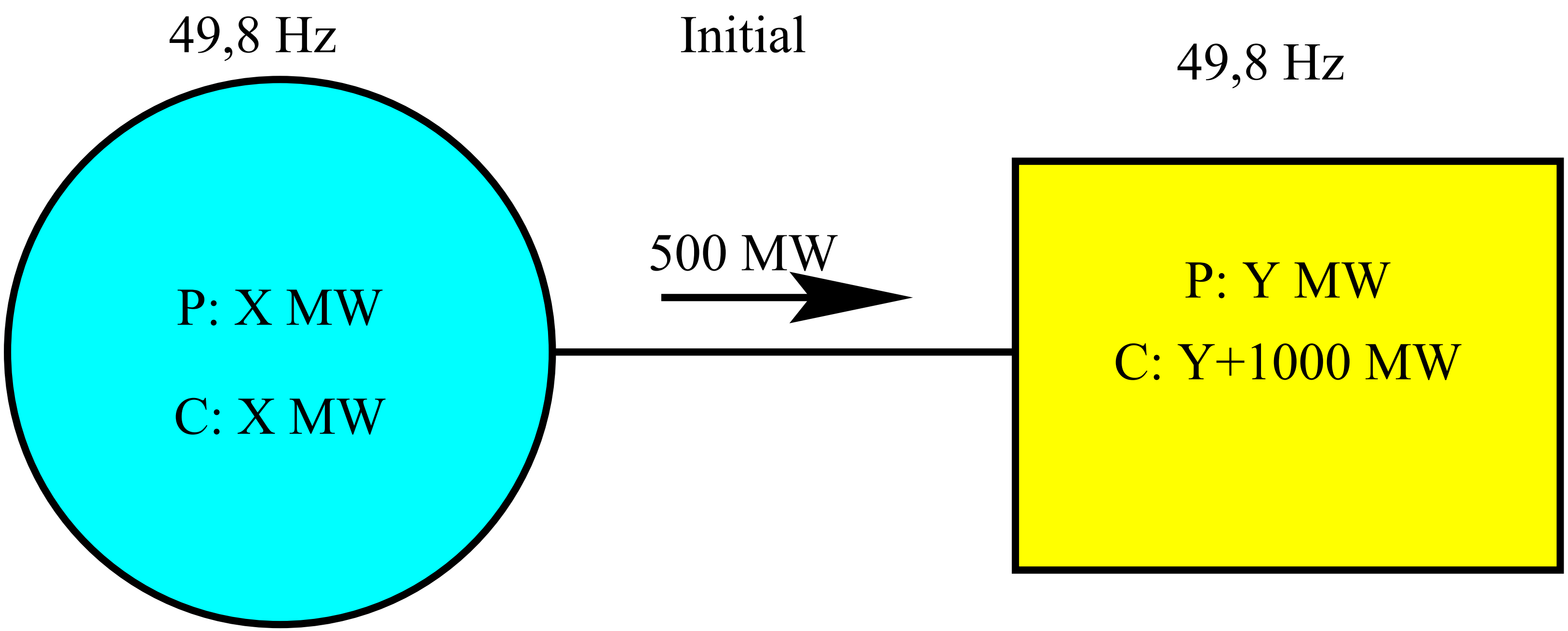
- *System frequency* is brought back to the scheduled value
- Balance between *generation* and *consumption* within each area
- Primary control is not impaired
- Centralized `automatic generation control' adjusts set points
- ***Power sources are called secondary reserves***
- ***PI controlled:***

$$\Delta P_{di} = -K \cdot \in - \frac{1}{T_{\sec}} \int \in \cdot dt$$

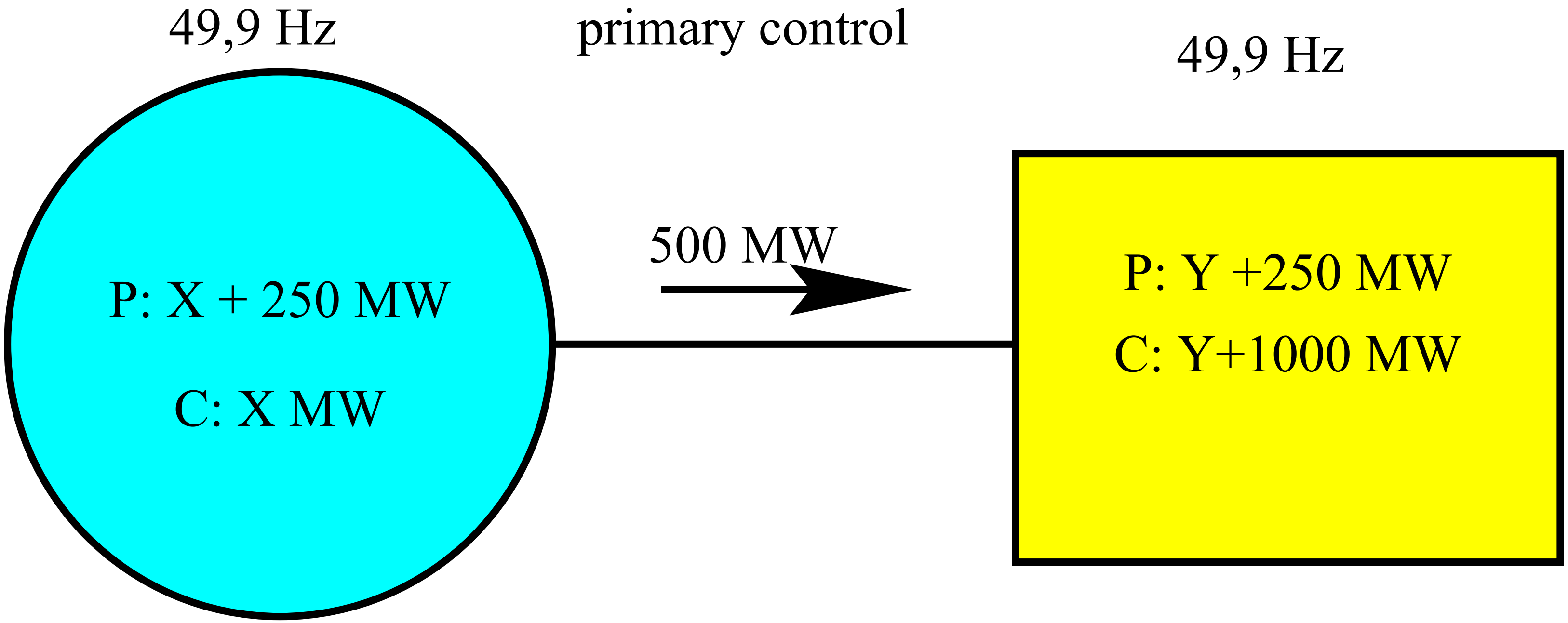
Primary and secondary control
Example



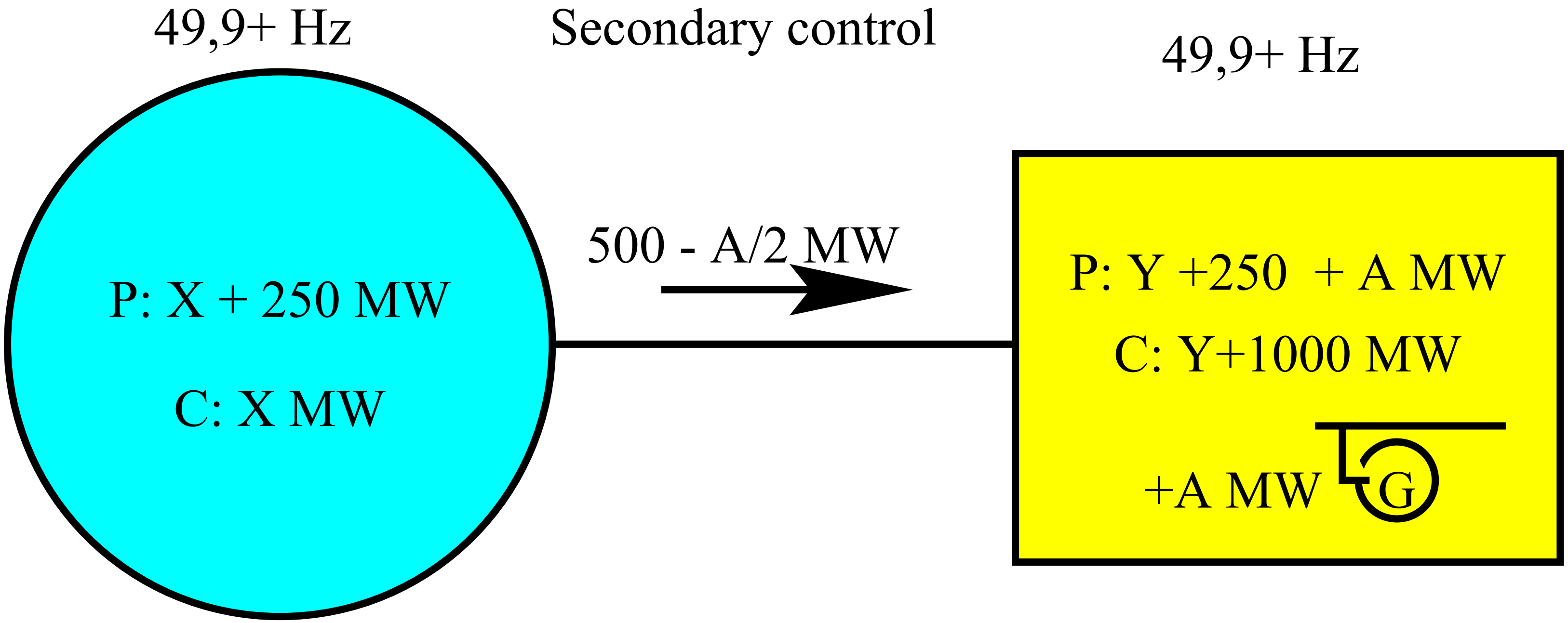
Primary and secondary control
Example (II)



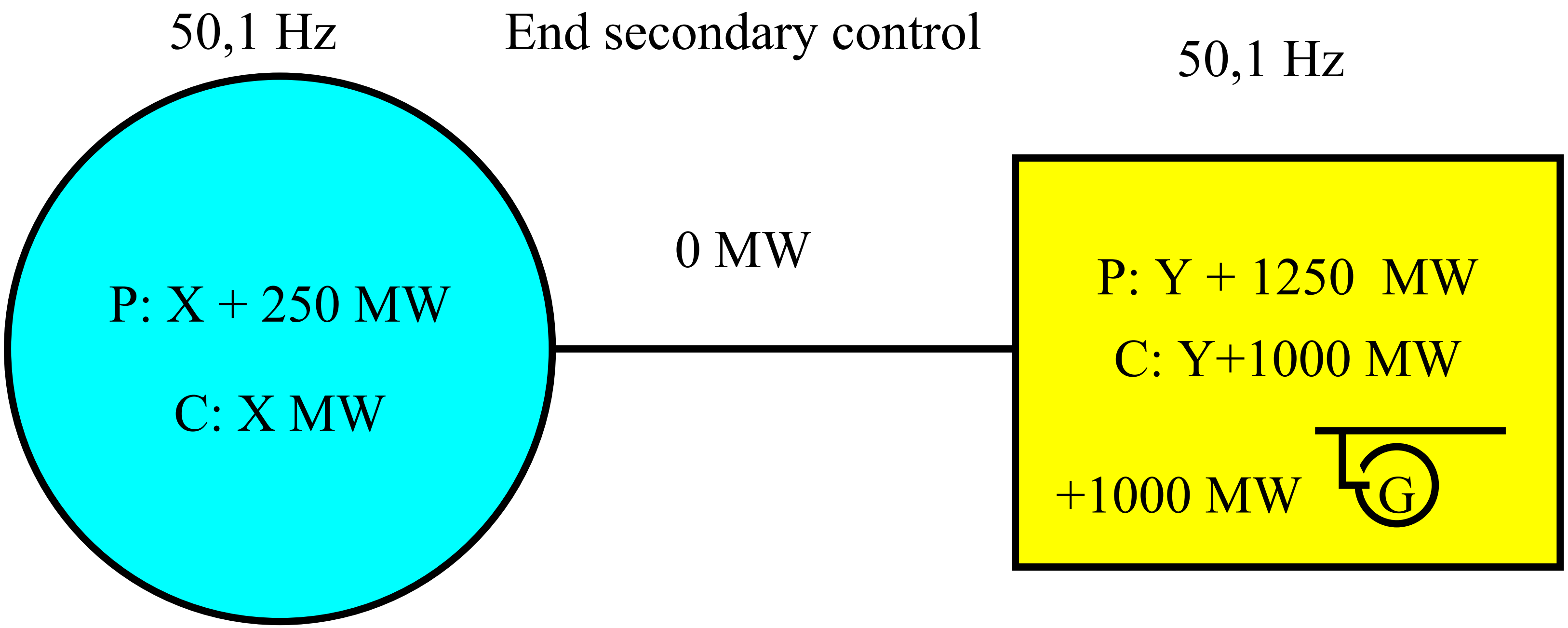
Primary and secondary control
Example (III)



Primary and secondary control
Example (IV)

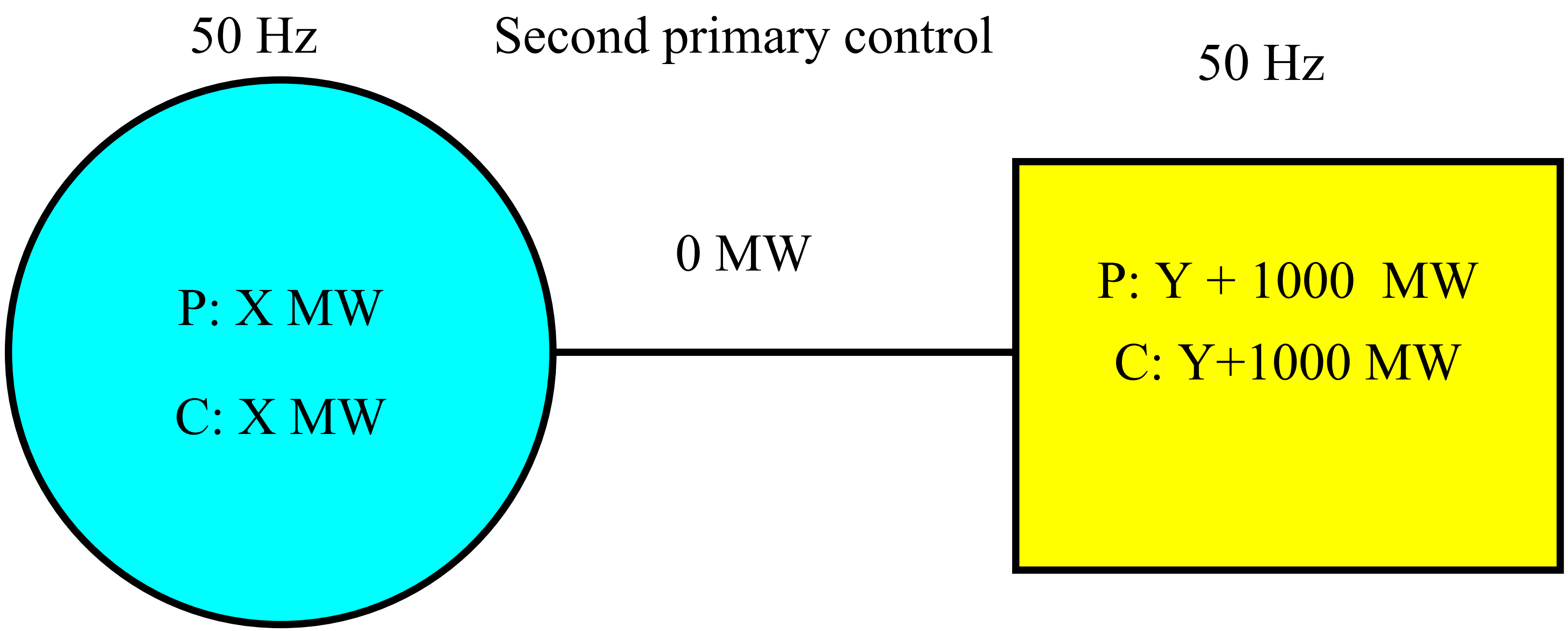


Primary and secondary control
Example (V)



Primary and secondary control Example (VI)

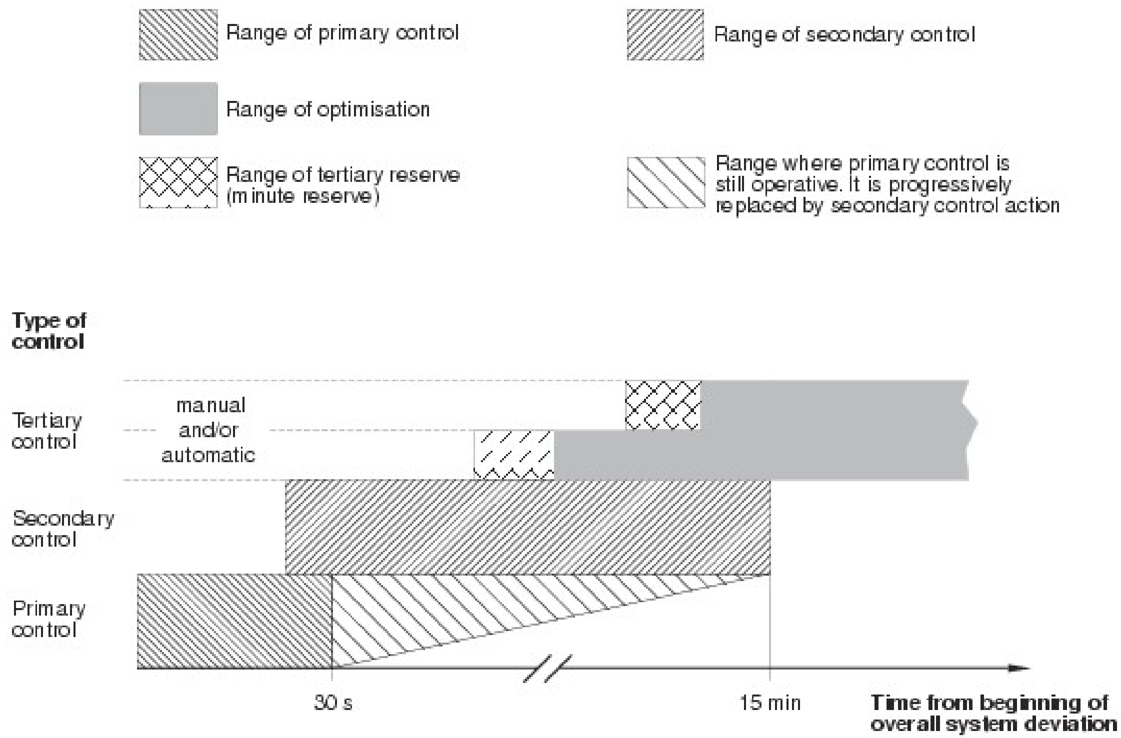
This phase happens simultaneously with the secondary control, and the “50.1 Hz” in reality doesn't occur



Tertiary control
Definition

- ***Automatic or manual set point change of generators and/or loads in order to:***
  - ***Guarantee secondary reserves***
  - ***Obtain best power generation scheme in terms of economic considerations***
    - *Cheap units (low marginal cost such as combined cycle or nuclear)*
    - *Highest security/stability*
    - *Loss minimalization*
    - *...*
- ***How?***
  - ***Redispatching of power generation***
  - ***Redistributing output of generators participating in secondary control***
  - ***Change power exchange with other areas***
  - ***Load control (shedding)***

Sequence overview



Time control

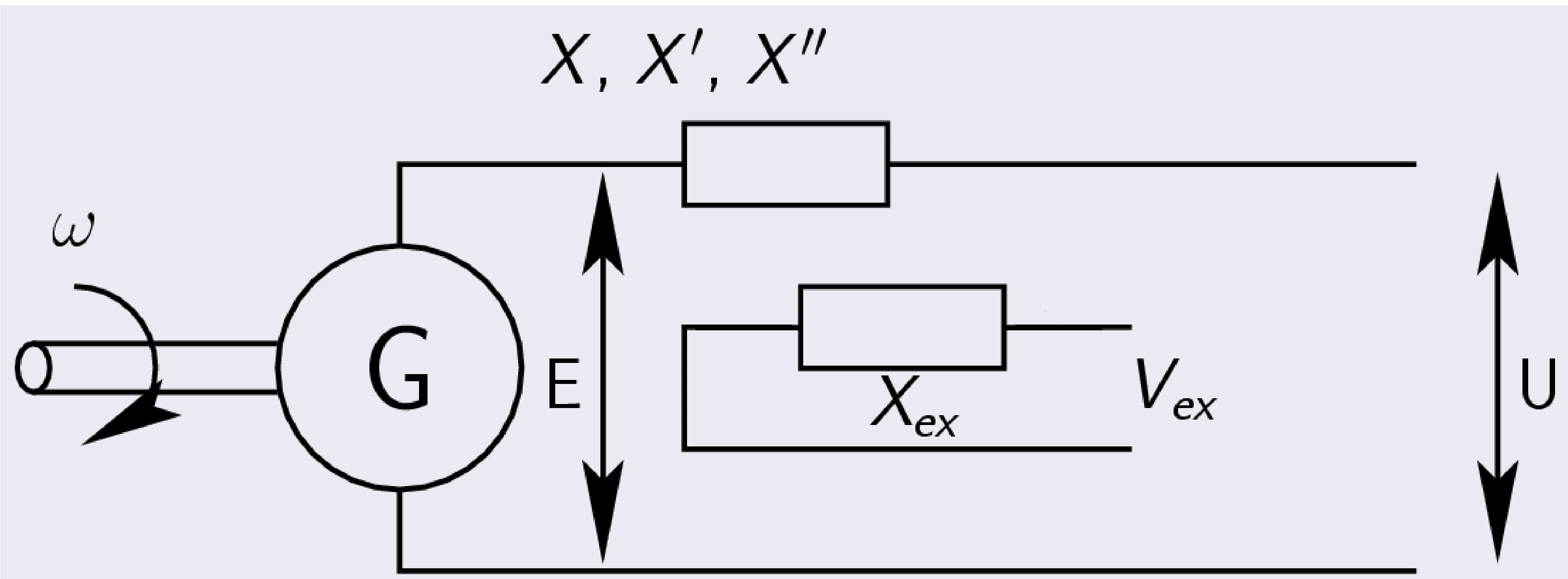
- Limit discrepancies between *synchronous time and universal time co-ordinated (UTC) within the synchronous zone*
- *Time difference limits (defined by UCTE)*
  - *Tolerated discrepancy: +/- 20 s*
  - ***Maximum allowed discrepancy under normal conditions: +/- 30 s***
  - ***Exceptional range: +/- 60 s***

- ***Sometimes `played' with (week – weekend)***

$$\int \Delta f(t) \cdot dt < 20s$$

Voltage control

- Voltage at busbar:
  - Voltage is mainly controlled by reactive power
  - Can be regulated through excitation, tap changers, capacitors, SVC, ...
  - Reactive power has a local nature



Voltage control

- Can the same control mechanism be used?
  - YES
- But
  - Good (sensitive) Q-production has to be available
    - Synchronous compensator: expensive
    - Capacitors: not accurate enough
    - SVC/STATCom: possible, but not cheap
  - U is `OK' between 0,95 and 1,05 p.u.
  - Reactive power is less price (fuel) dependent (some losses)

- Voltage is locally controlled

Voltage control Control scheme

- Automatic voltage regulator (e.g. IEEE AVR 1)