7. FREQUENCY CONTROL AND REGULATING RESERVES

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Purpose of frequency control and regulating reserves

- Keep the balance between demand and supply of electricity
- Balance is measured with frequecy of system

Power system differenetial equation

$$dWk/dt = Pg - Pc$$

where

Wk = kinetic energy of all rotating machines = $\frac{1}{2} J \omega^2$

Pg = power generation

Pc = power consumption

J = torque of machines

ω = angular speed (rad/s)

Frequency drop without regulation

$$df = dPg/Kn \left(1 - e^{-fNKn/(2Wk) \times t} \right)$$

where

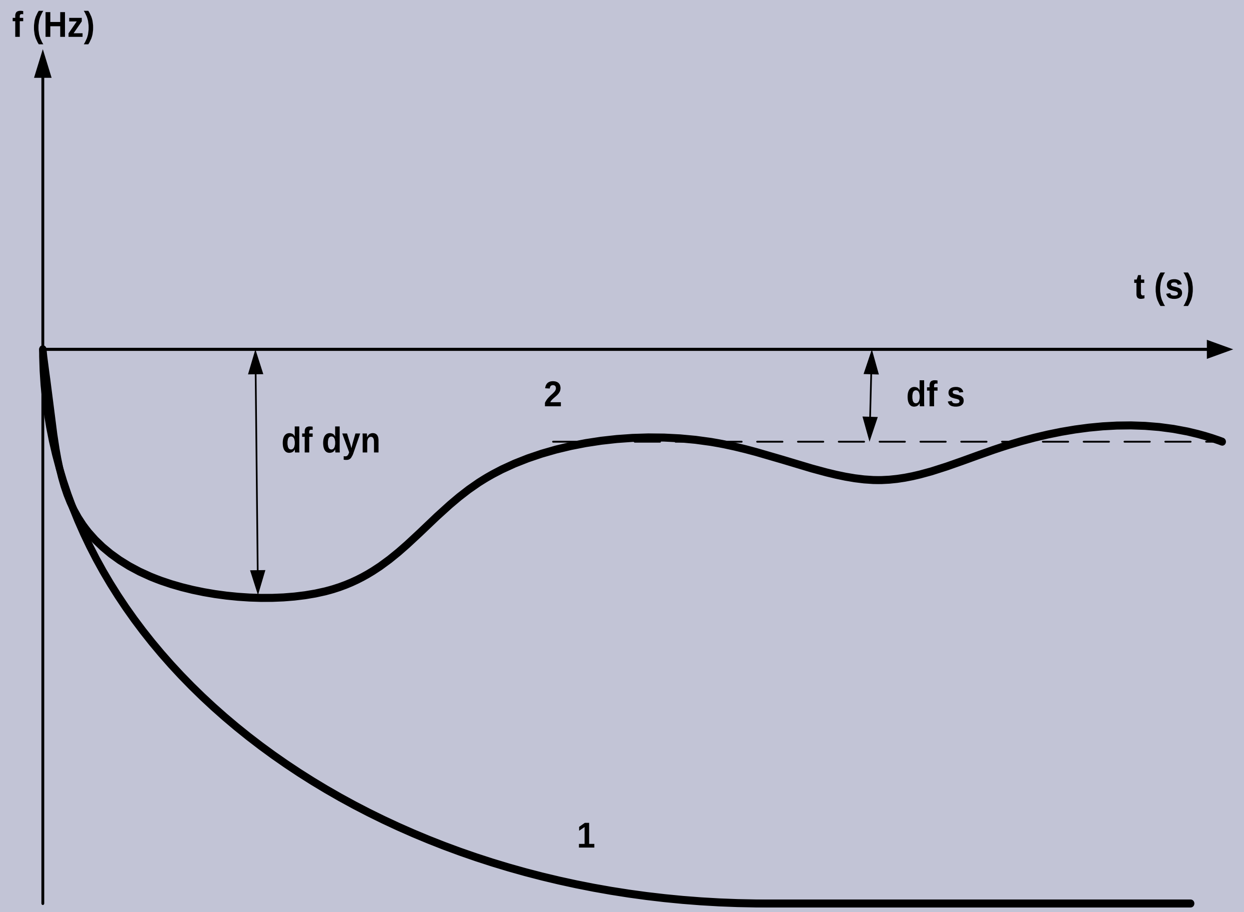
$2Wk/(fNKn)$ = time constant (T) (5 - 10 s)

Kn = natural control gain of the network (Hz/MW)

1/Kn = self regulation power (typically 1-2 % of total capacity)

Deficit causes a frequency drop

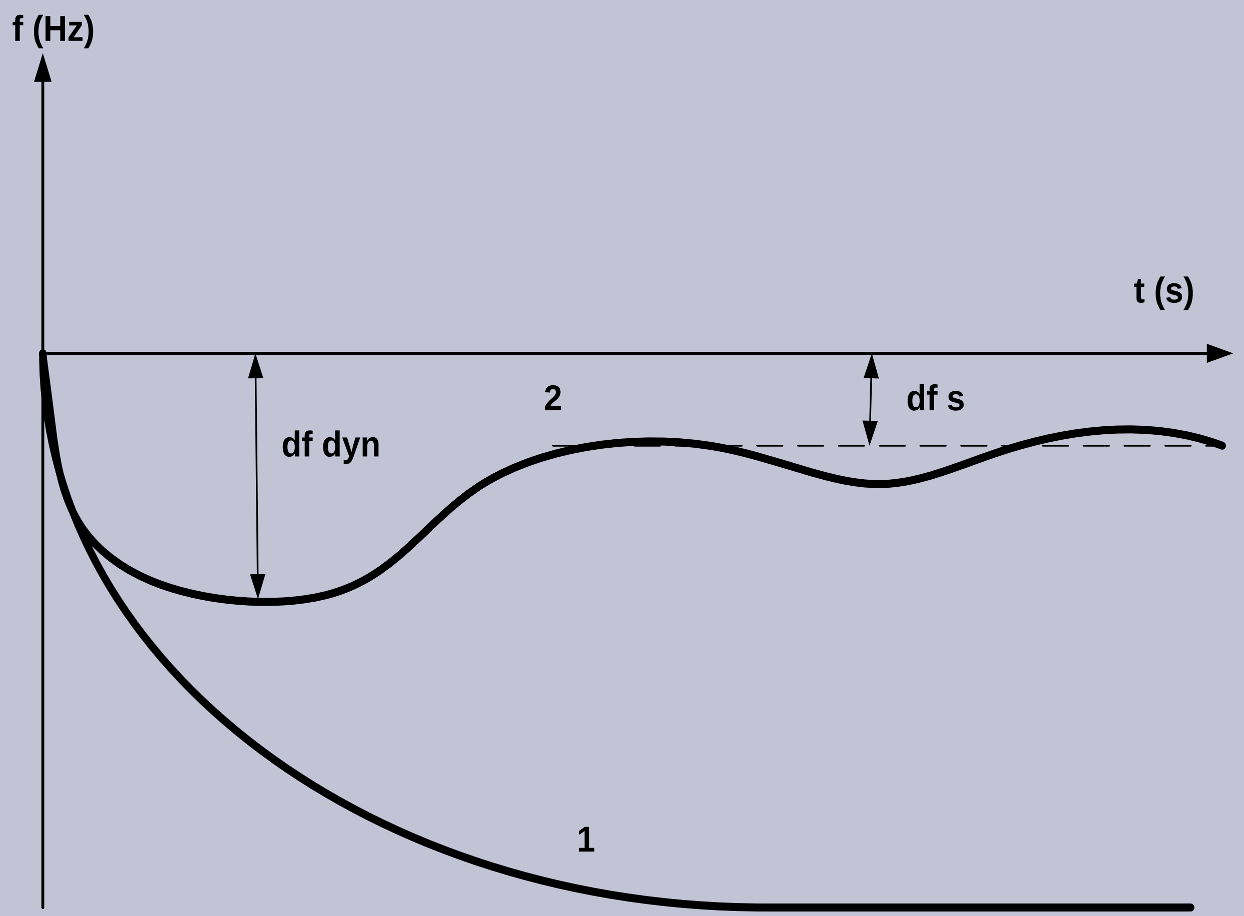
without regulation (line 1) and
with regulation (line 2)



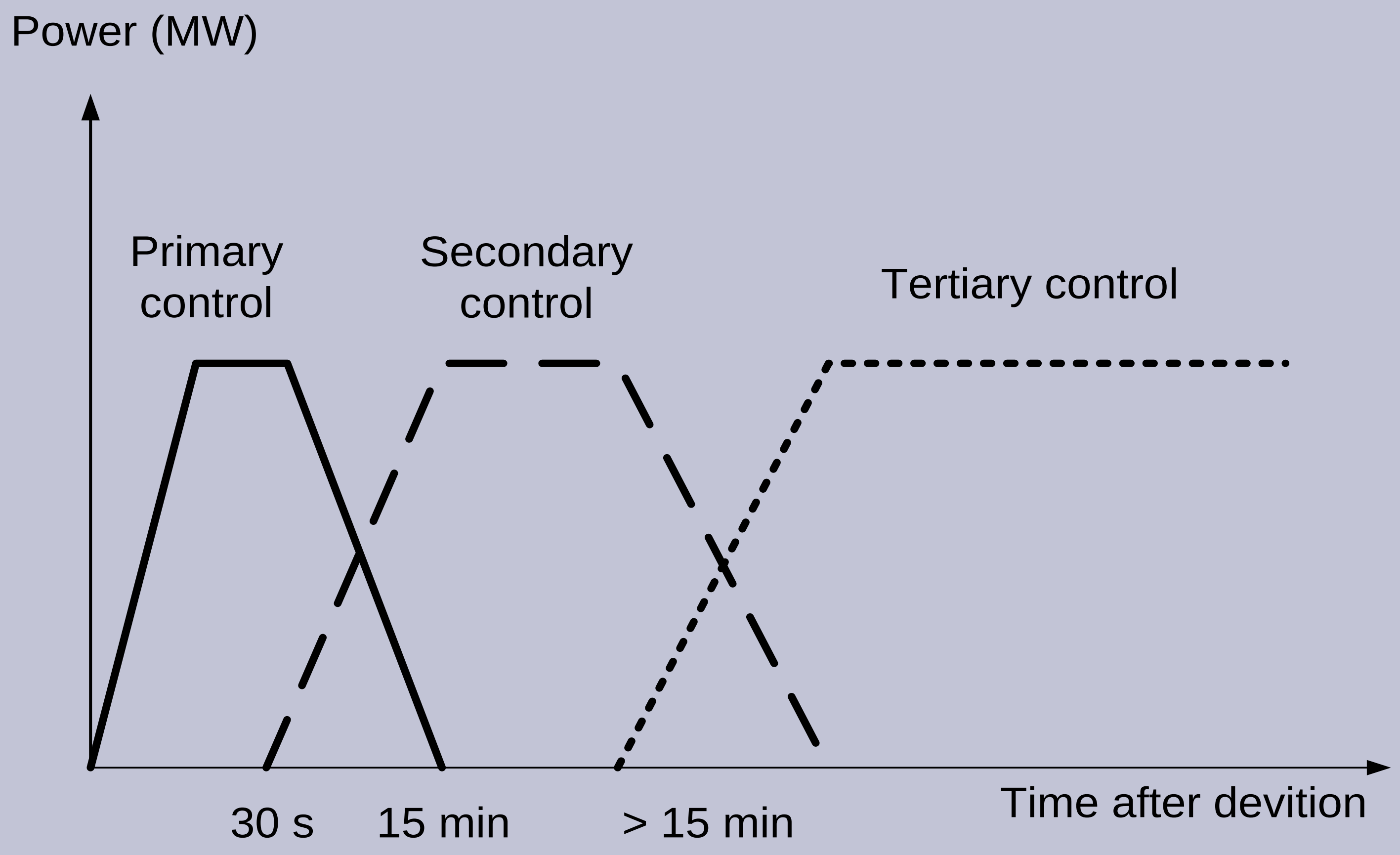
Without regulation

- Loss of 10 % of generation causes a frequency drop by 3 – 5 Hz within a minute
- The maximum allowed deviation is typically 0.1 – 0.2 Hz (dfs), thus regualtion is needed

Regulation reserves limit the frequency deviation to dfs

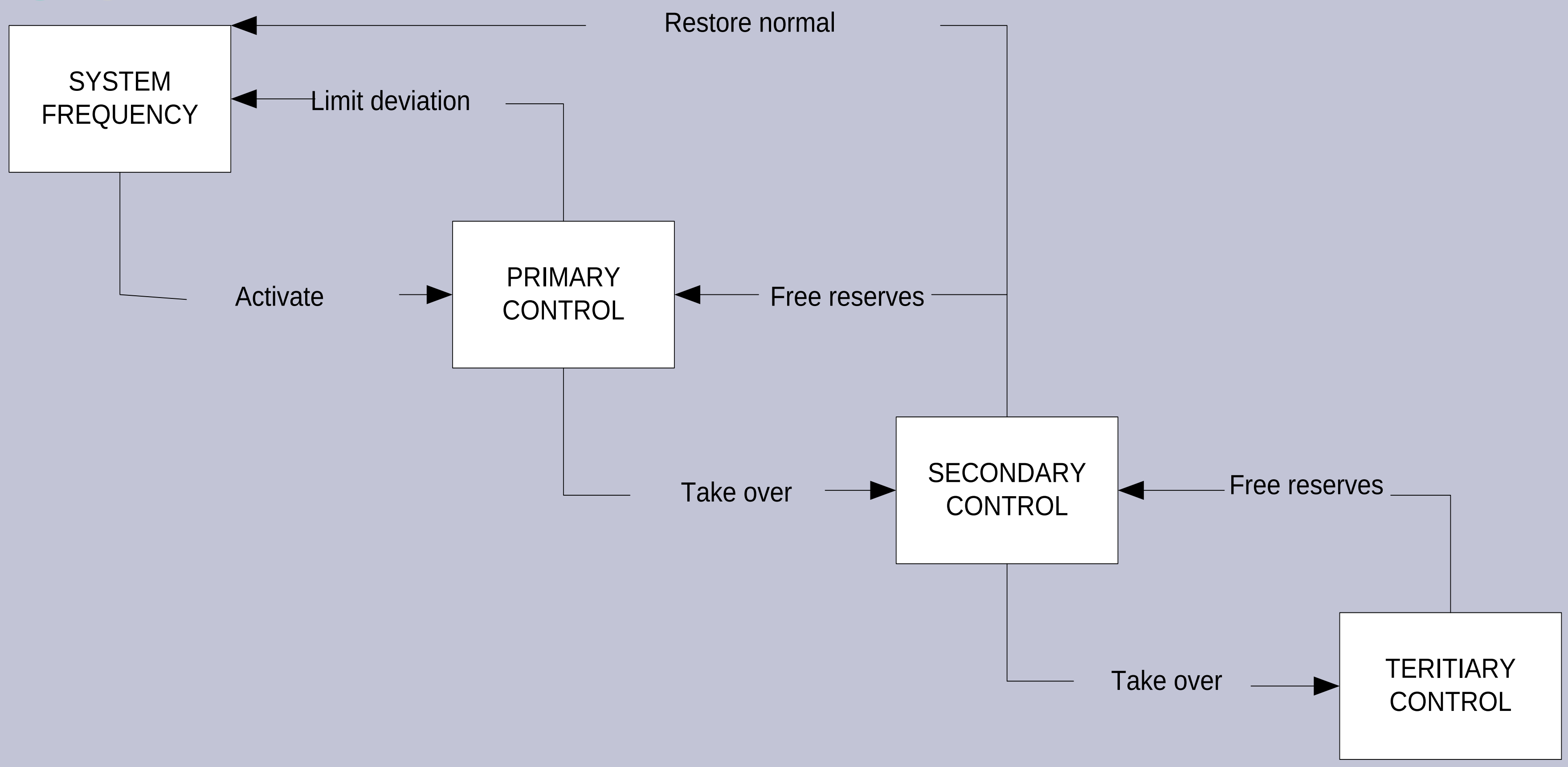


Classification of regulating reserves (UCTE)*



UCTE = Union for the Co-ordination of Transmission of Electricity

Sequence of actions of primary, secondary and tertiary control



Primary control reserves

Primary control reserves

Actions taken within 5 – 30 seconds by generator droop control

Generators measure the frequency and immediately change the output according the formula:

$$dP = - Pgn/s_G/f_n \times df$$

Primary control, continued

$$dP = - Pgn/s_G/f_n \times df = - Rp \times df$$

where

dP = change in generator output (MW)

Pgn = nominal output of generator (MW)

s_G = generator droop (%)

fn = nomnal frequency

df = change in power system frequency

Rp = regulating power = - $Pgn/S_G/f_n$

Primary control, continued

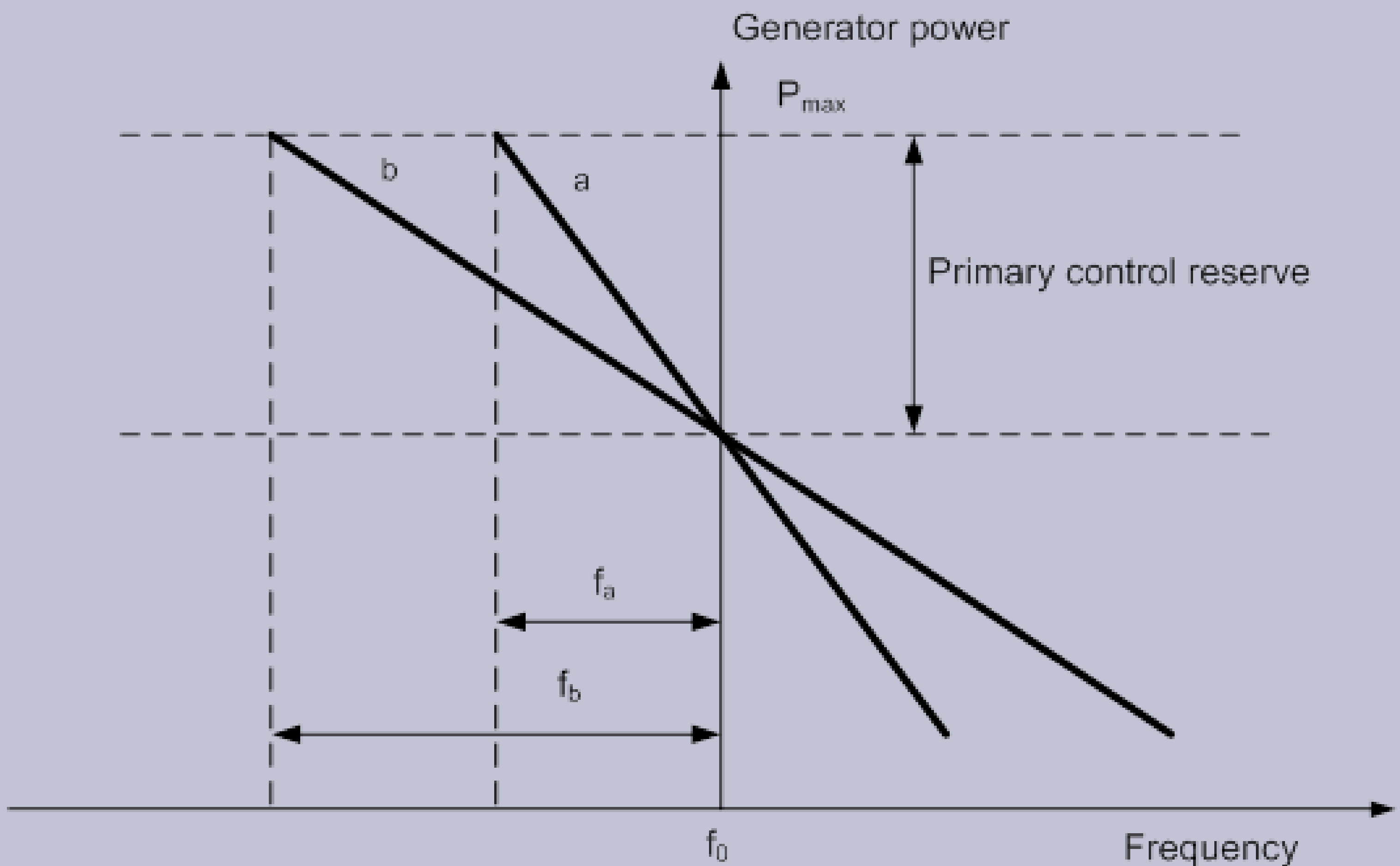
- If the frequency deviation is eleminated the output becomes the same as it was before the disturbance (system is then restored)

- The primary control is Proportional control (P-control), where the output change (dP) is directly proportional to frequency deviation (df)

Primary control, continued

Two generators (a and b)

with different droop



Two generators (a and b) with different droop

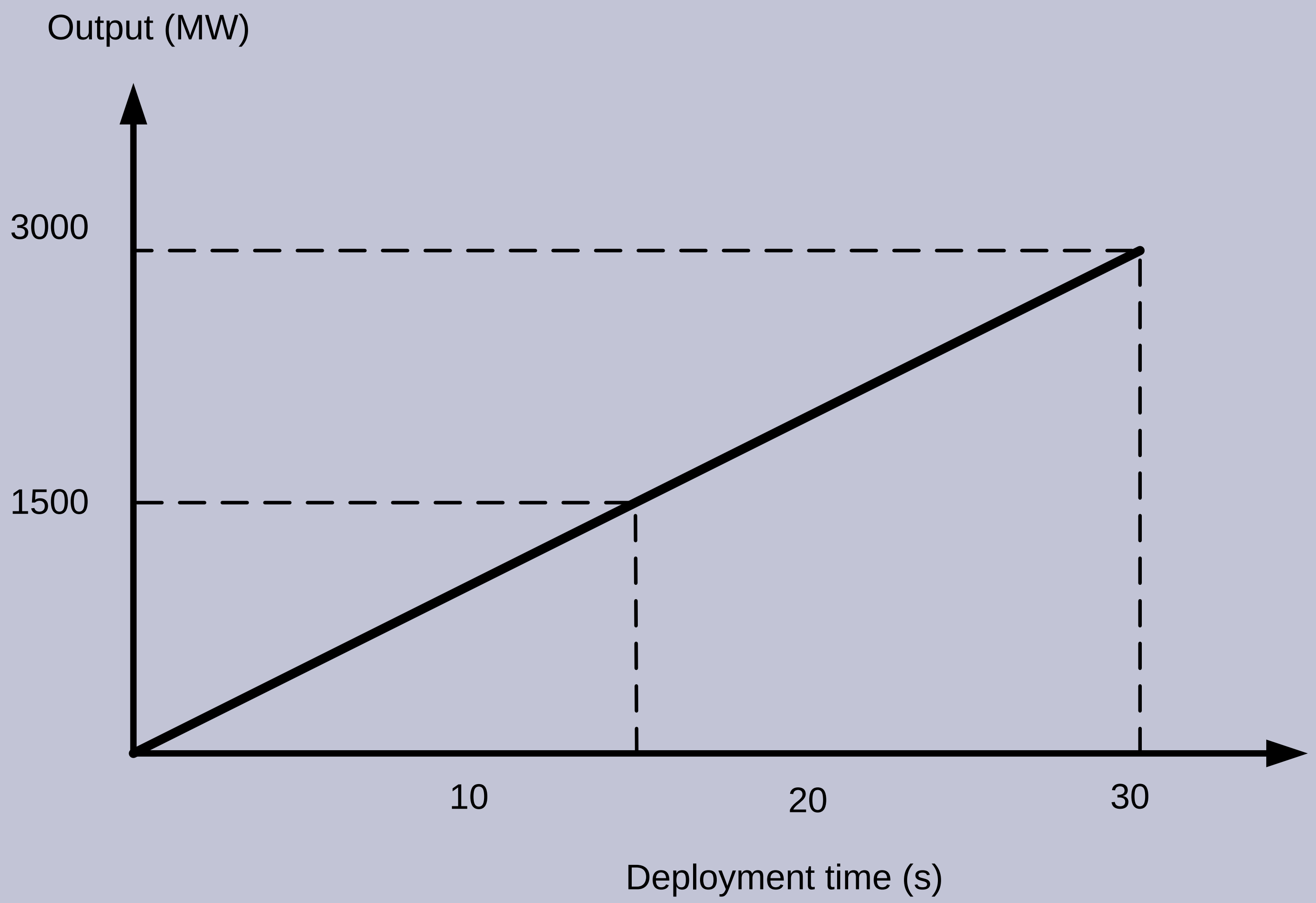
Generator b needs much larger deviation in frequency (f_b) than generator a (f_a) to change the output by the same relative amount

(Primary control reserve)

Need of primary control reserves

- UCTE 3000 MW (Continental Europe)
  - 3000 MW or equivalent of two 1500 MW nuclear plants or lines trip at the same time
- Eastern Interconnection (USA)
  - 3000 MW = largest interconnection
- NORDEL (North Europe)
  - Continuous control = 600 MW/0.1 Hz
  - Frequency response = 1000 MW, if frequency drop to 49,5 – 49,9 Hz

Primary control reserve deployment time (UCTE)



Primary control reserve deployment time

- UCTE
  - 1500 MW in 15 s
  - 3000 MW in 30 s
- Nordel
  - 300 MW in 5 s
  - 1200 MW in 30 s

* Note: the first 5 seconds are critical (see slide 7)

Secondary control reserves (regulating reserves in USA)

Secondary control reserves Functions

- Should reset the primary control reserves in 5 – 15 minutes to be ready for next disturbance
- Should correct the frequency deviation within allowable limit
  - +/- 0.1 Hz in Nordel
  - +/- 0.2 Hz in UCTE

Secondary control reserves Control formula

$$dP = - K \times ACE - 1/Tr \int ACE\, dt \; *$$

where

dP = output set point of secondary controller

K = gain of P – controller

ACE = Area Control Error

Tr = time constant of secondary controller

* Note: The control action dP increases by integral formula, if the deviation of ACE remains constant (PI-type controller)

Secondary control reserves

Area Control Error (ACE)

$$ACE = dB + K \times df$$

Where

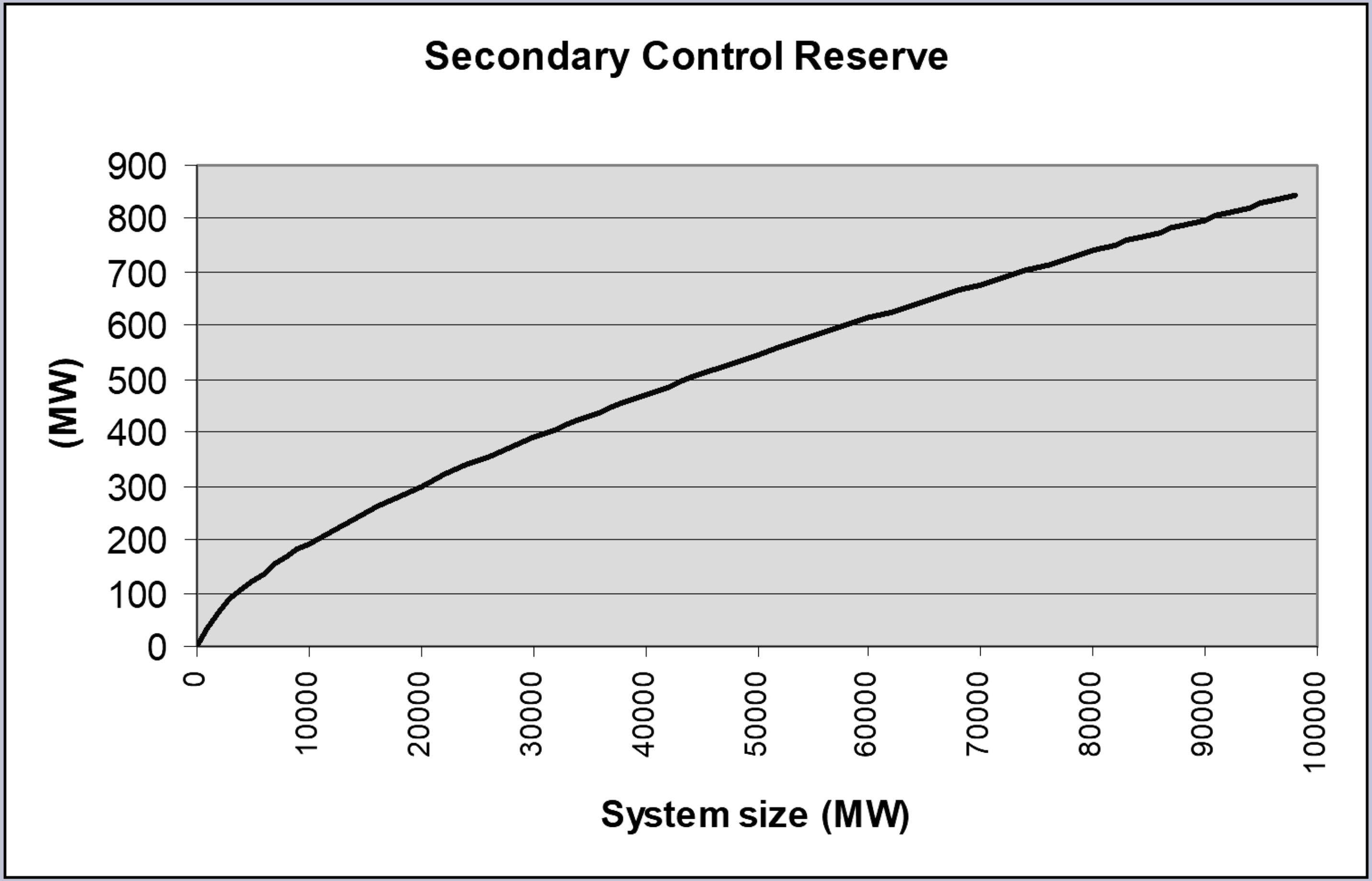
dB = deviation in power balance (= Generation-Load + Import - Export)

df = deviation of frequency from (f_N)

K = dependency between deviation of power and system frequency

Note: ACE is calculated in about five to ten second intervals by computers in the dispatch center

Secondary control reserves
Reserve requirements (UCTE)



Secondary control reserves
Reserve requirements

- UCTE (Continental Europe)
  - 3000 MW system 100 MW = 3 %
  - 10000 MW system 200 MW= 2 %
  - 60000 MW system 600 MW= 1 %
- PJM (USA)
  - Forecasted day peak load 1.1 %
  - Forecasted night peak load 1.1 %
- Nordel (North-Europe)
  - No specific requirement given

Secondary control reserves

Automatic Generation Control (AGC) and manual control

- AGC (USA and UCTE)
  - Dispatch center computers measure ACE and send setpoints for regulating power plants automatically
- Manual (Nordel)
  - Dispatch center operators call to regulating power plants by phone and ask to change the set points

Secondary control reserves

Response times

- 5 min
  - PJM (USA)
  - Germany
- 10 min
  - Nordel
  - California (USA)

Secondary control reserves

Compliance factor (USA)

CF = ACE/(-10B) x df

Where

CF = compliance factor

ACE = Area Control Error (slide 22)

10B = bias setting of control area (MW/Hz)

df = frequency deviation

Secondary control reserves

Compliance factor (USA)

- Compaliance factor is measured in each ten minute periods for monthly statistics
- If 90 % of compliance factors during a month are better then required, then everything is OK
- If not, regulators may demand more new reserves or faster response times from existing regulation reserves

Secondary control reserves

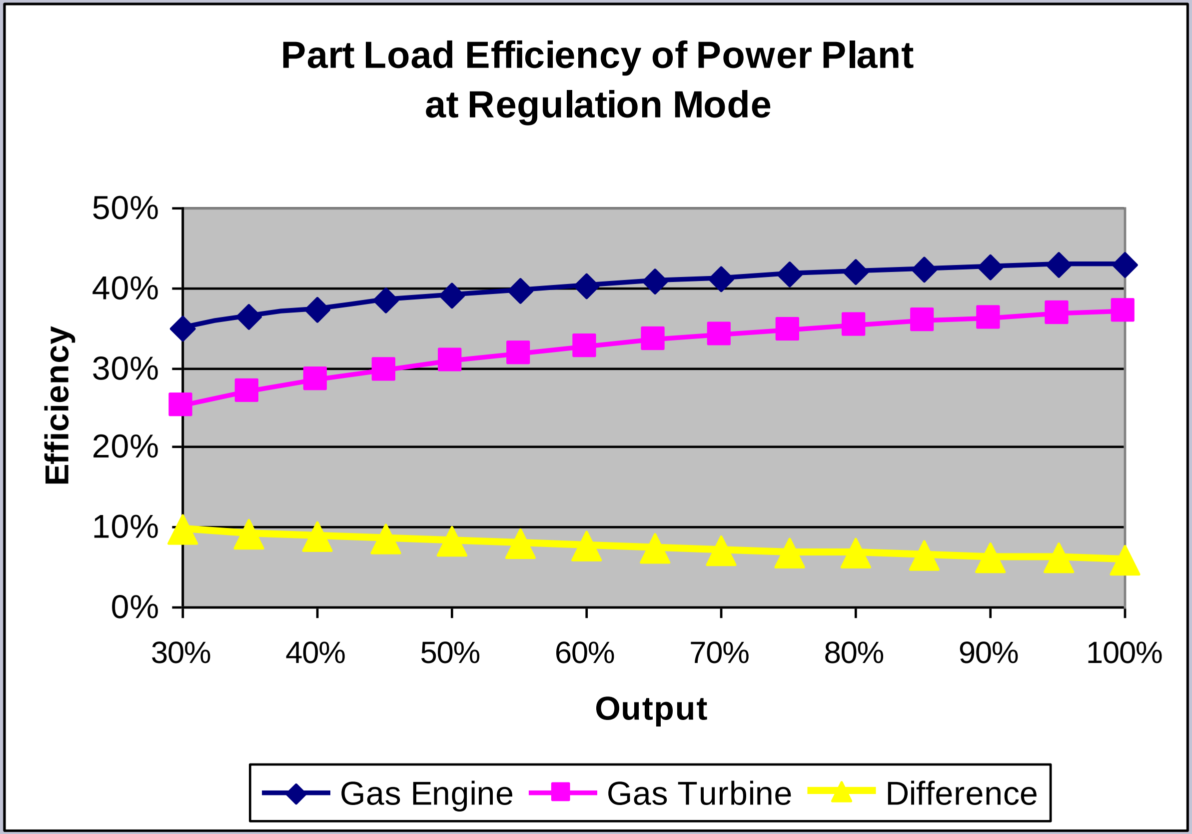
Power plant actions

- Gas engine plant operates initially at 70 % output
- It can then change its output +/- 30 % in five minutes
- Ramp rate = 30 %/5 min = 6 %/min*

*See futher details of ramp rates of various power plants in presentation Fundamentals of power plants

Secondary control reserves

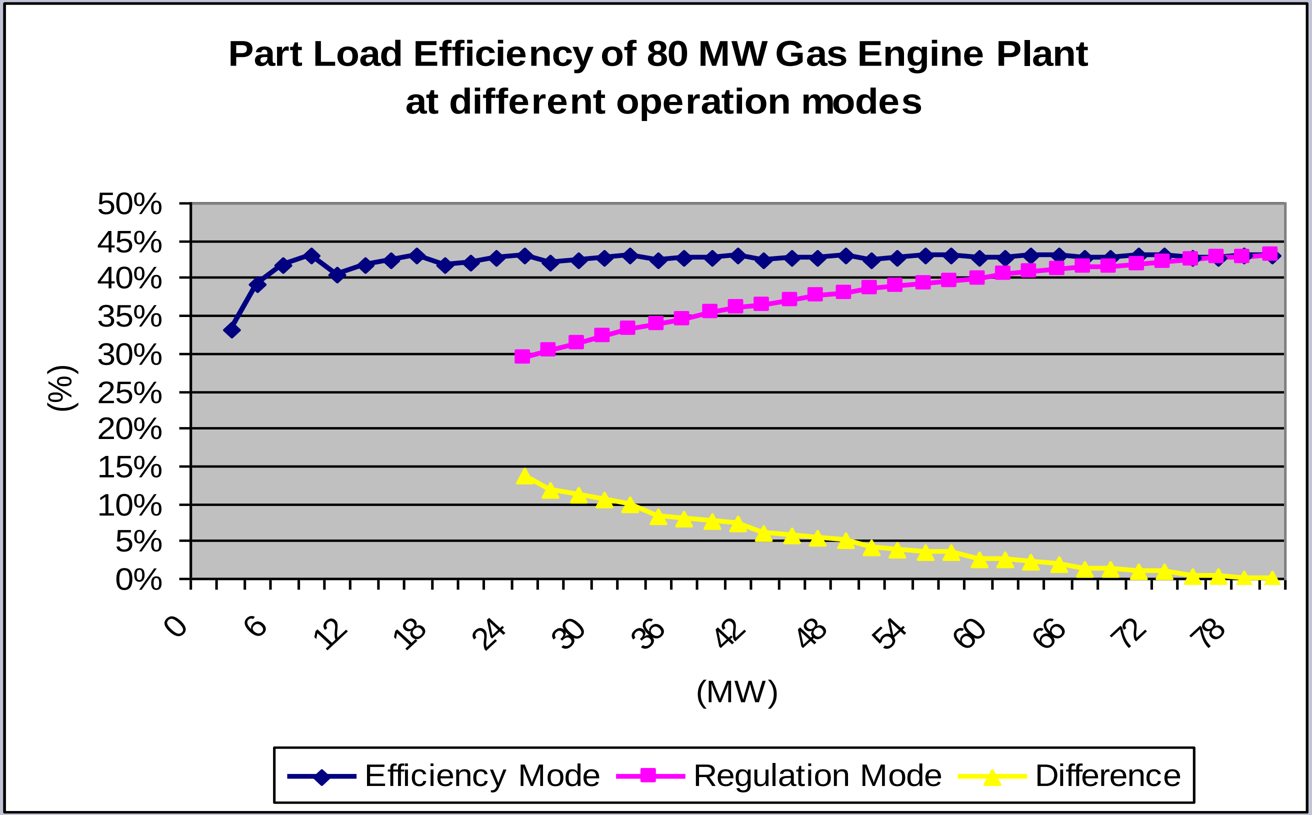
Part load efficiency is important



Efficiency at 70 % load: GE 41 % and GT 34 %

Secondary control reserves

Part load efficiency of 80 MW gas engine plant*



*** At high Efficiency Mode engines are started one by one**
At Regulation Mode all engines run at same output

Secondary control reserves

Summary

- Secondary control systems correct the frequency deviation using PI-type regulation
- Regulation can be made automatically by AGC or mannually by the operator
- The power plants which have highest part load efficiency can deliver reguation with the lowest costs

Tertiary control reserves
Balance control

Tertiary control reserves

Balance control

- Tertiary control is a responsibility of each Load Serving Entity (LSE)
- LSE should balance its load, generation, sales and purchases in each balancing interval
- Balancing interval varies from 15 minutes to 60 minutes depending on the country

Tertiary control reserves

Balance control

- LSE can
  - Use selfgeneration for balance control
  - By balance difference from balance provider
  - Pay penalties to System Operator
- LSE:s prefer
  - Power plants which can be used in balance control and regulation

Critical situations

- Morning ramp
  - All resources are needed to increase power from 50 % to 100 % within two hours
- Television pickup
  - Olympic games or other sport happenings can increase load by 10 - 20 % in some minutes

Summary

- Transmission system operator (TSO) uses frequency control and regulation to keep the electricity power balance in control from seconds to one hour
- Load Service Entities (LSE) try the keep the their balance by flexible power plants within one hour and sell regulation services to TSO

For details see reference text book
”Planning of Optimal Power Systems”

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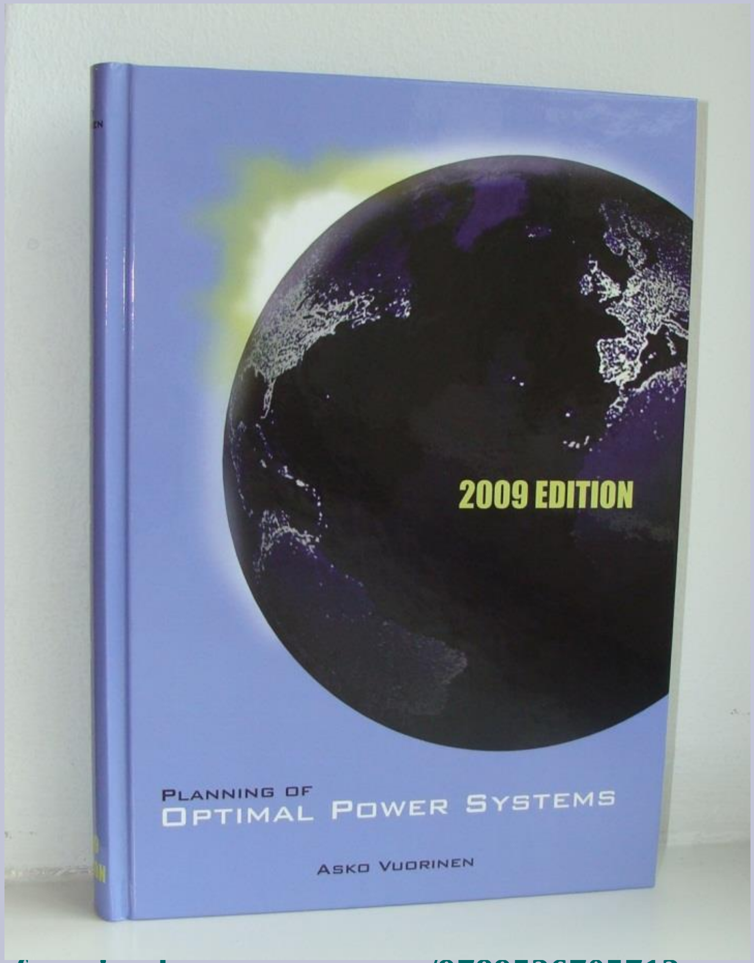

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