SPINNING RESERVE IMPACT ON POWER SYSTEM STABILITY

Dr. Ir. Nanang Hariyanto

Technical Issues

System Frequency Dynamics

- System Stored Energy

$$\frac{dE_{mech}}{dt} = P_{gen} - P_{load}$$

System Frequency Dynamics

The Swing Equation

$$\frac{df}{dt} = \frac{f_0}{2H} \cdot \frac{P_{gen} - P_{load}}{S_{rated}}$$

Where,

df/dt	= Rate of change in frequency
f_o	= Base frequency, 50Hz
H	= Inertia constant of system
P_{gen}	= Active power generation
P_{load}	= Active power demand
S_{rated}	= Total MVA rating of rotating plant

Factors Affecting Frequency Decay

$$\frac{df}{dt} = \frac{f_0}{2H} \cdot \frac{P_{gen} - P_{load}}{S_{rated}}$$

- Overload (ΔP)
- System inertia (H)
- Frequency dependency of load (d)
- Frequency control systems:
  - governor action (spinning reserve)
  - load shedding

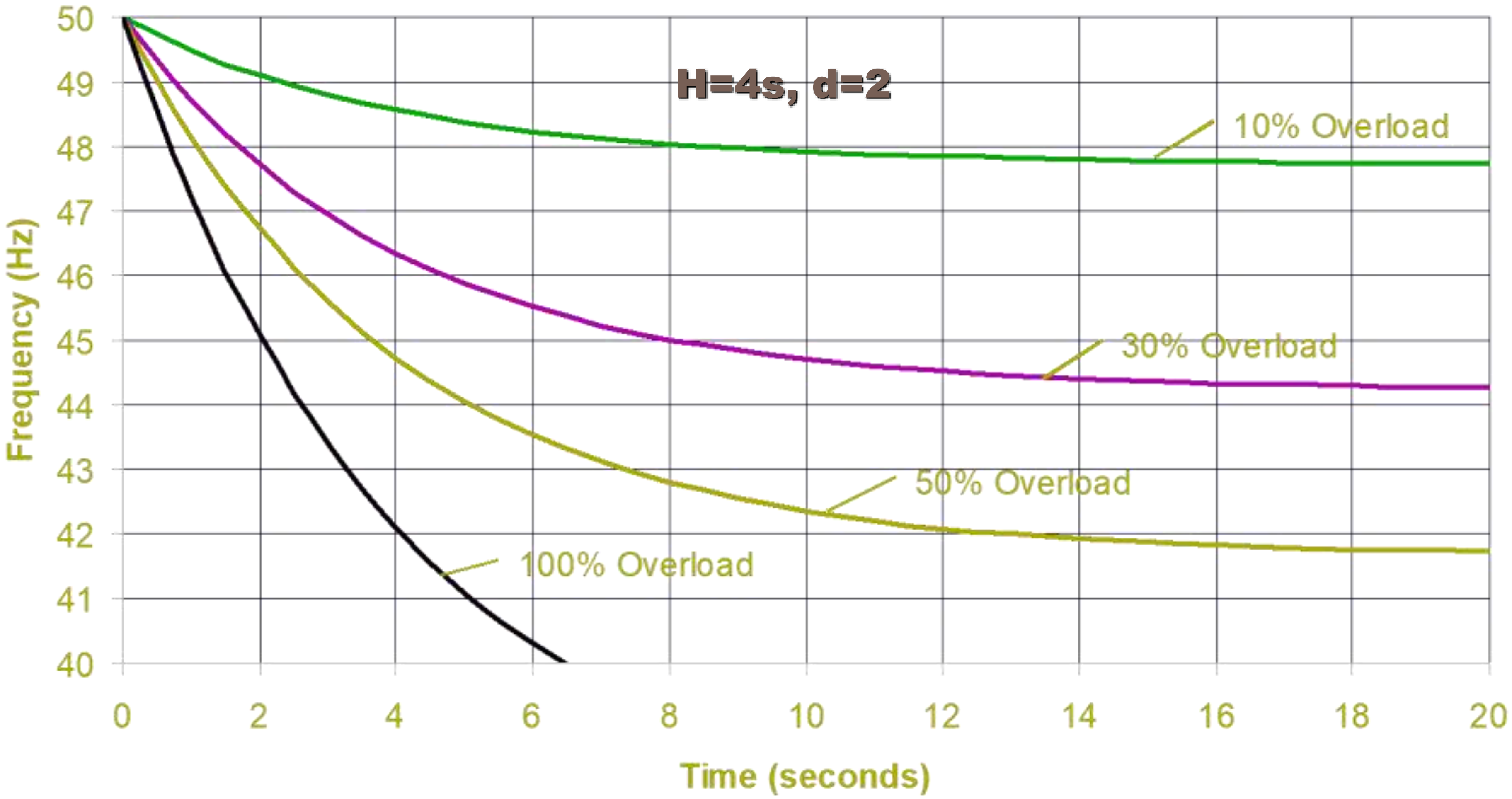
Overload Influence

- Overload is the difference between the active power demand and the active power generated, as a percentage of power generation, i.e.

$$\Delta P=(P_{gen} - P_{load})/ P_{gen}$$

- The greater the overload, the greater the rate of frequency decay
- Small islanded systems: overloads tend to be larger

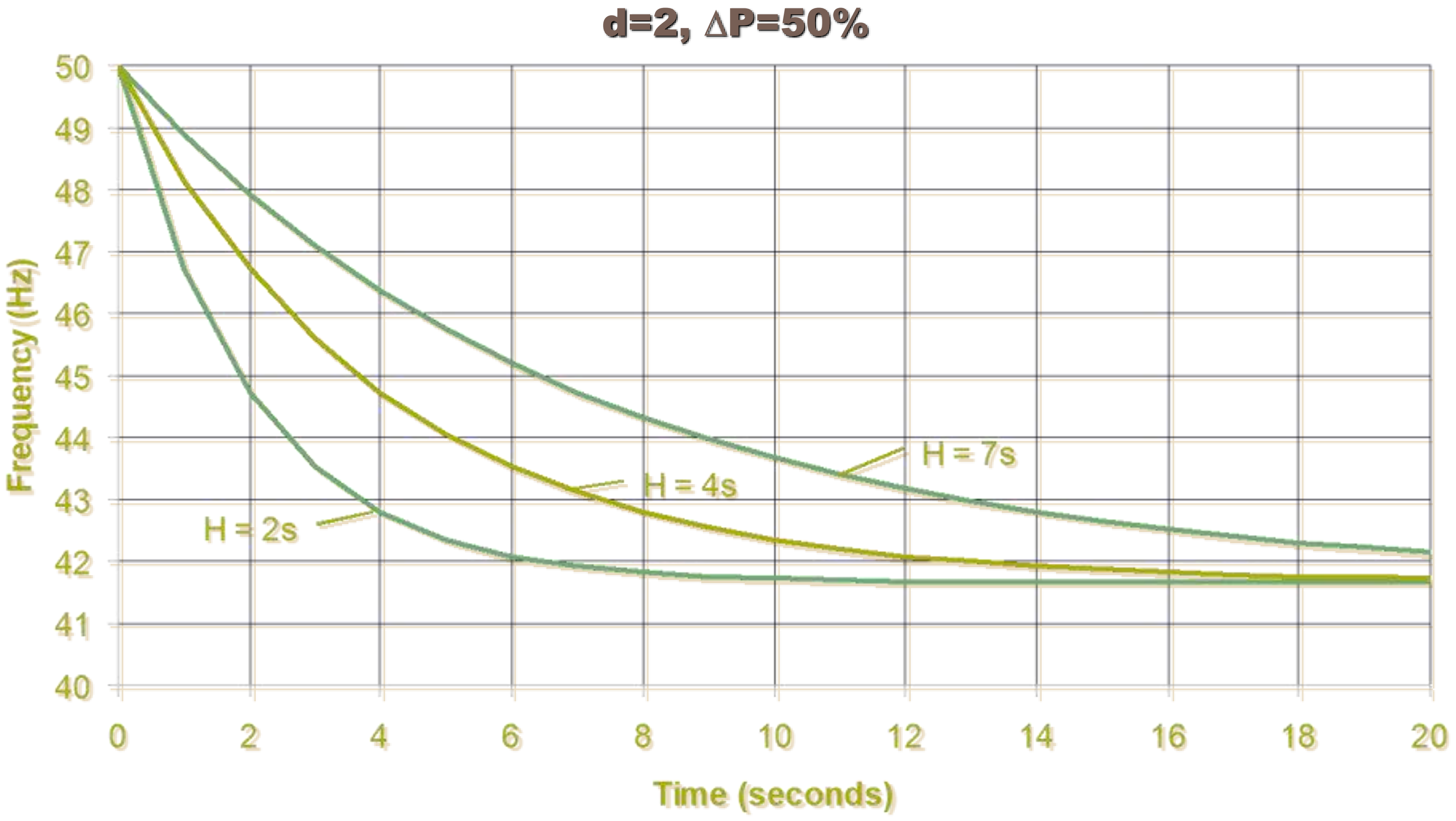
Overload Influence



Inertia Influence

- The rotating plant of the system will tend to maintain its rotational speed due to its moment of inertia (H)
- Determines initial rate of decay of frequency for a given overload
- The smaller the inertia of the rotating plant, the faster the decay in frequency
- Small islanded systems have relatively small system inertia

Inertia Influence

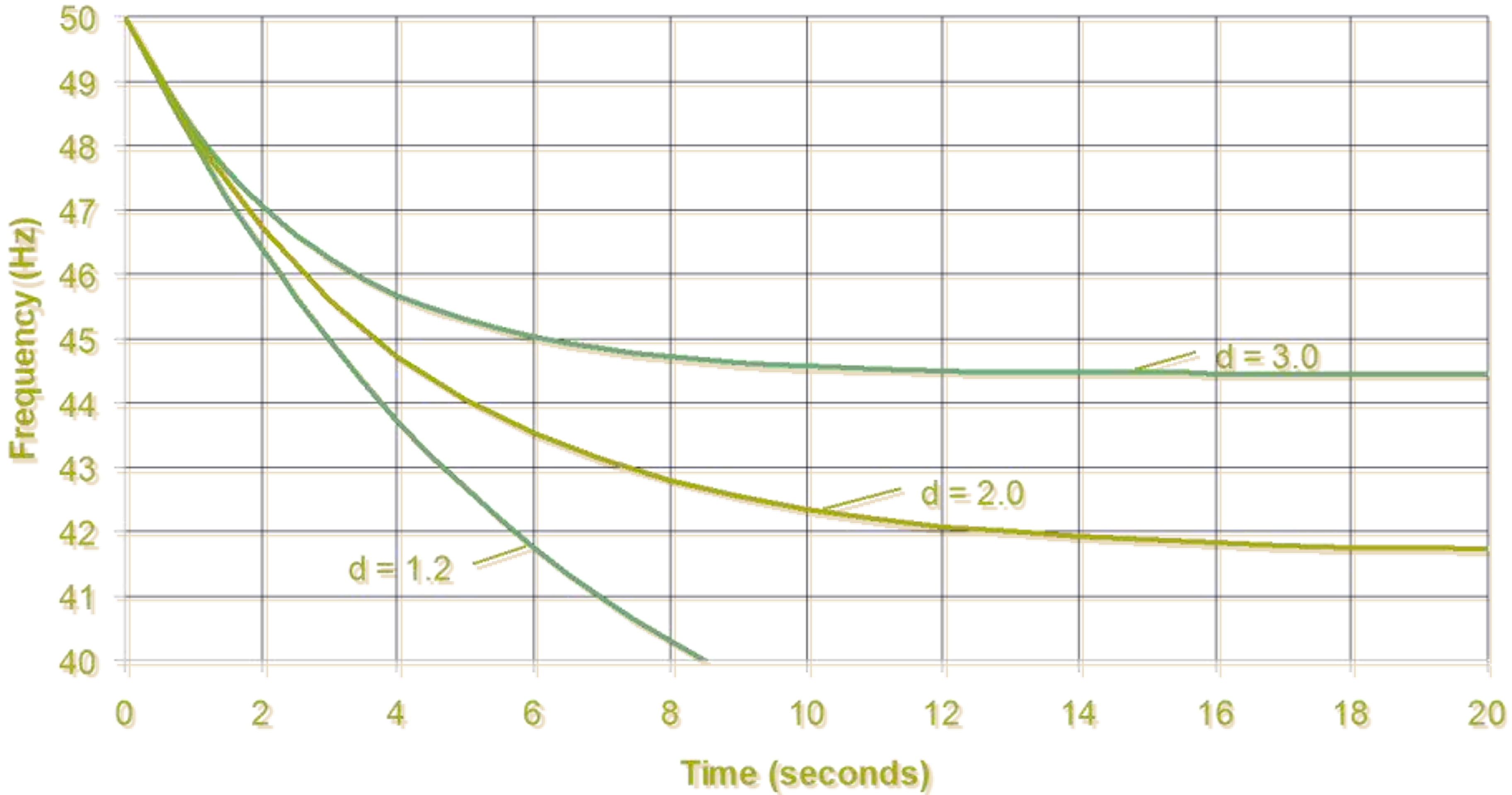


Load Self-regulation Influence

- As system frequency decays, system demand decreases.
- This effect due primarily to the dynamic behaviour of motor loads
- Load Reduction Factor :

$$\frac{\Delta P_{load}}{P_{load0}} = d \cdot \frac{\Delta f}{f_0}$$

Load Self-regulation Influence

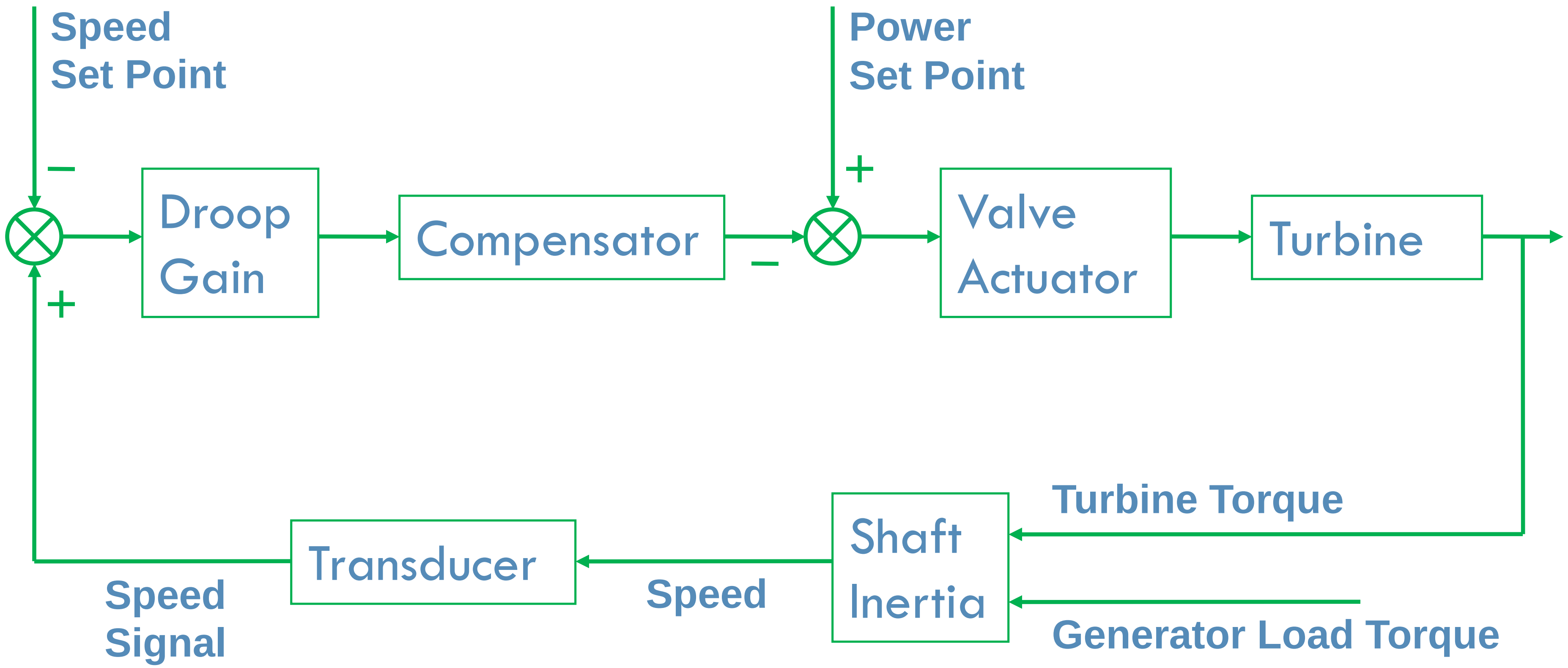


Frequency Control Tools

- Governor Action – automatic control of power generation to match system load and maintain frequency.
- Under-frequency load shedding – automatic shedding of discrete loads to prevent total system collapse.

Governor Action

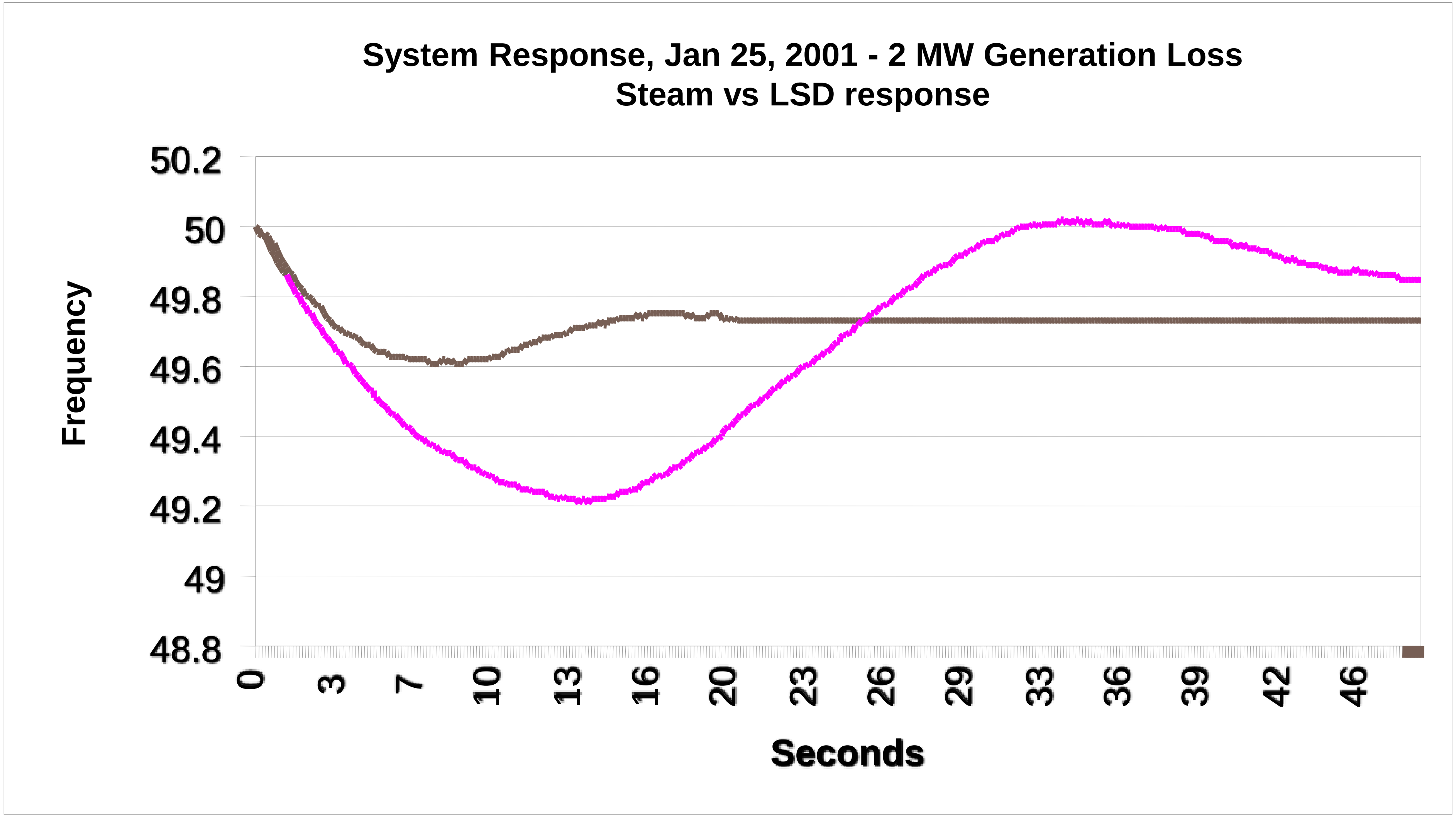
Power-Frequency Control Loop



Governor Action

- The governor droop is the percentage variation in frequency to which the governor responds by effecting a 100% change in power output
- The governor compensator is a filter of the input signal that allows for tuning of governor response dynamics

Governor Action



Under-frequency Load Shedding

- UFLS is a last resort, emergency action
- Emphasis on saving the system from collapse
- In small isolated systems:
  - Overloads tend to be larger
  - System Inertia is smaller
  - More drastic, faster action is required
  - 80-100% of load subject to shedding in principle

Under-frequency Load Shedding

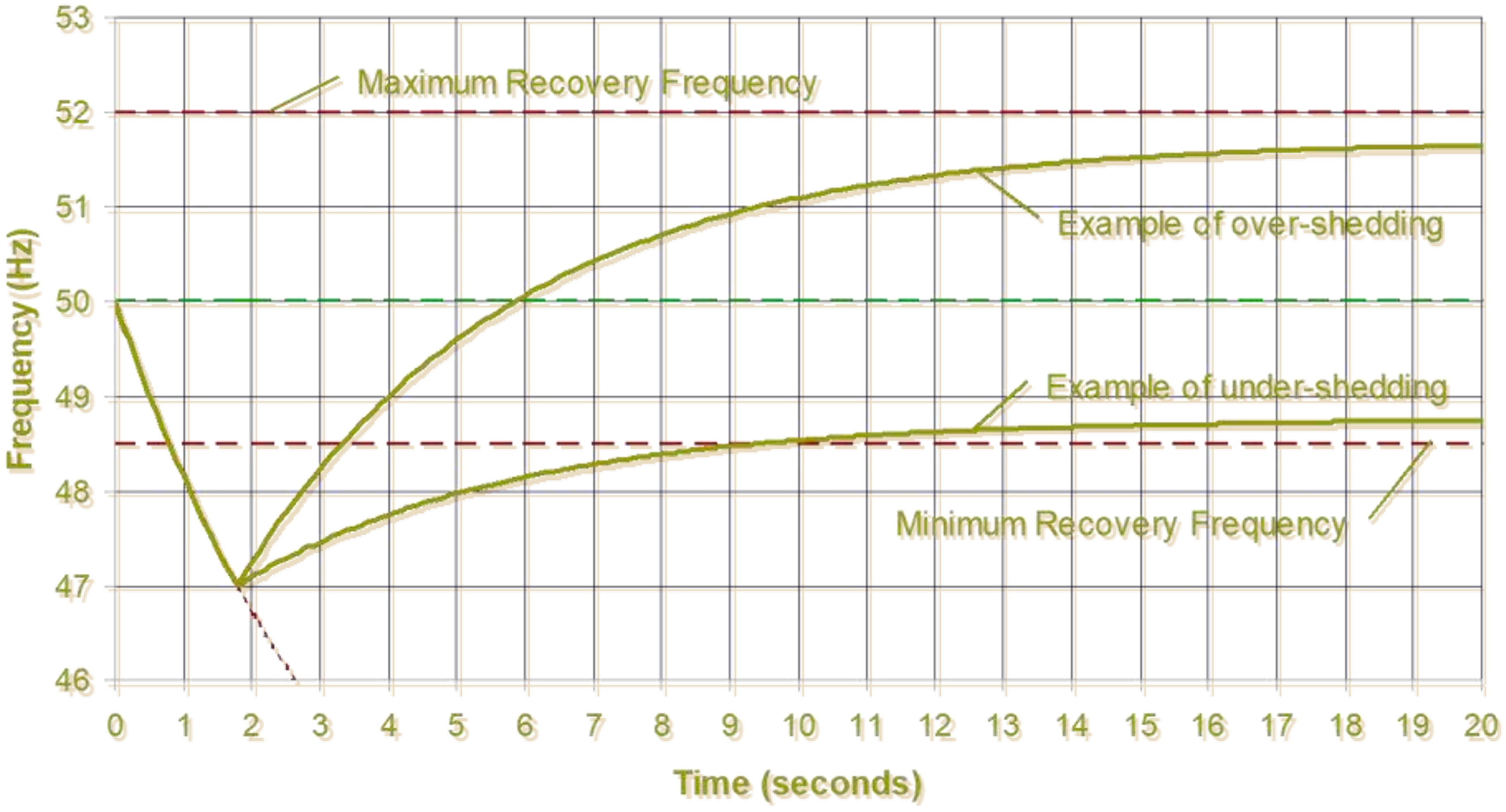
Design Considerations:

- Spinning Reserves
  - Level
  - Distribution
- Load Shedding Parameters
  - Maximum anticipated overload
  - Amount of load to be shed
  - Frequency thresholds
  - Step size and number of steps
  - Time delays
  - Priorities and distribution

Under-frequency Load Shedding

- Generating plant is highly sensitive to frequency drop
  - Low pressure turbine stages
  - Motor driven auxiliaries
  - Mechanical fatigue is cumulative
- Transient minimum frequency thresholds
- Recovery frequency band
  - Governor action - Spinning reserves
  - System dispatcher action
    - Manual increase of load shedding
    - Start-up additional generation

Under-frequency Load Shedding

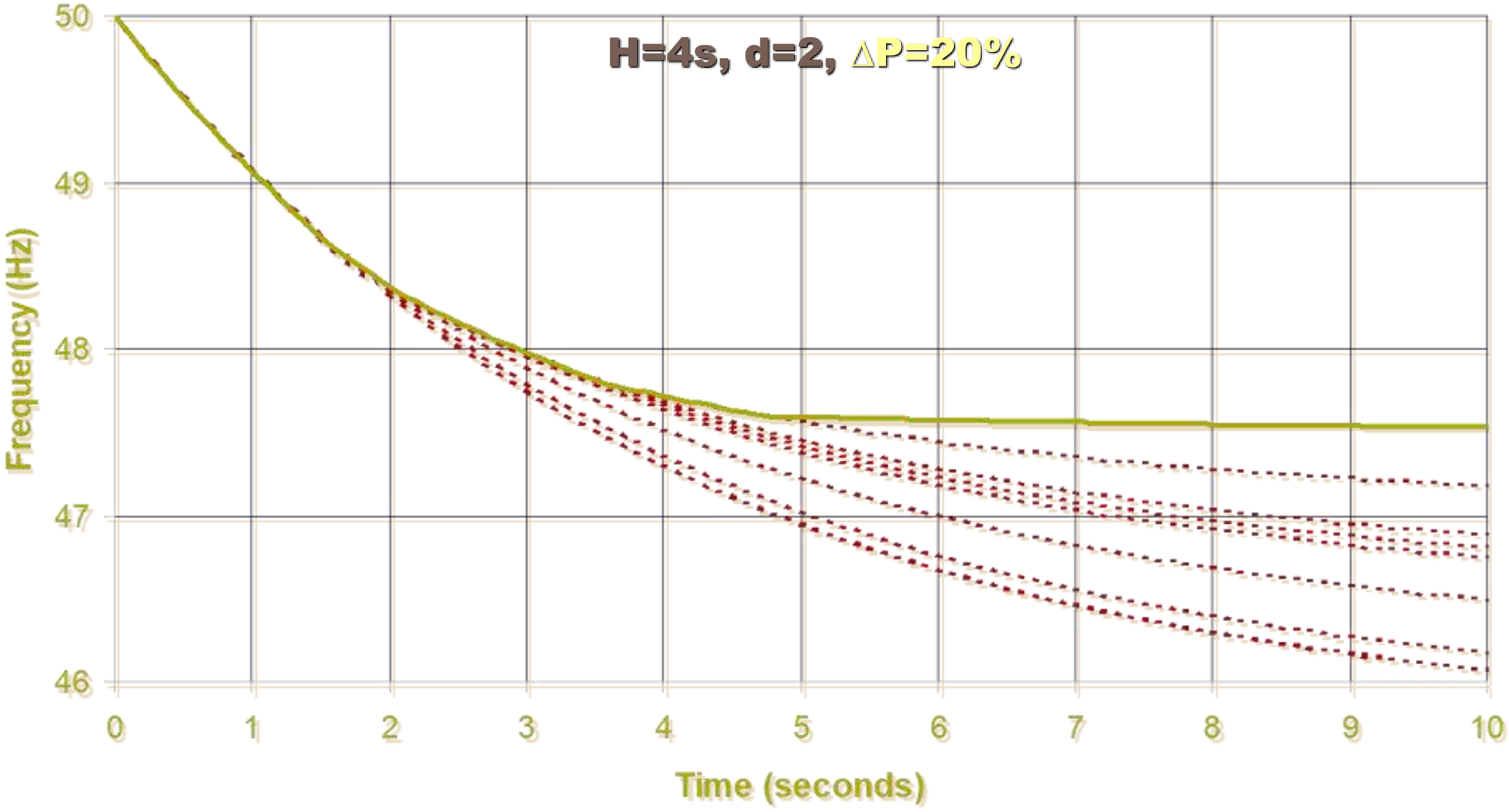


Under-frequency Load Shedding

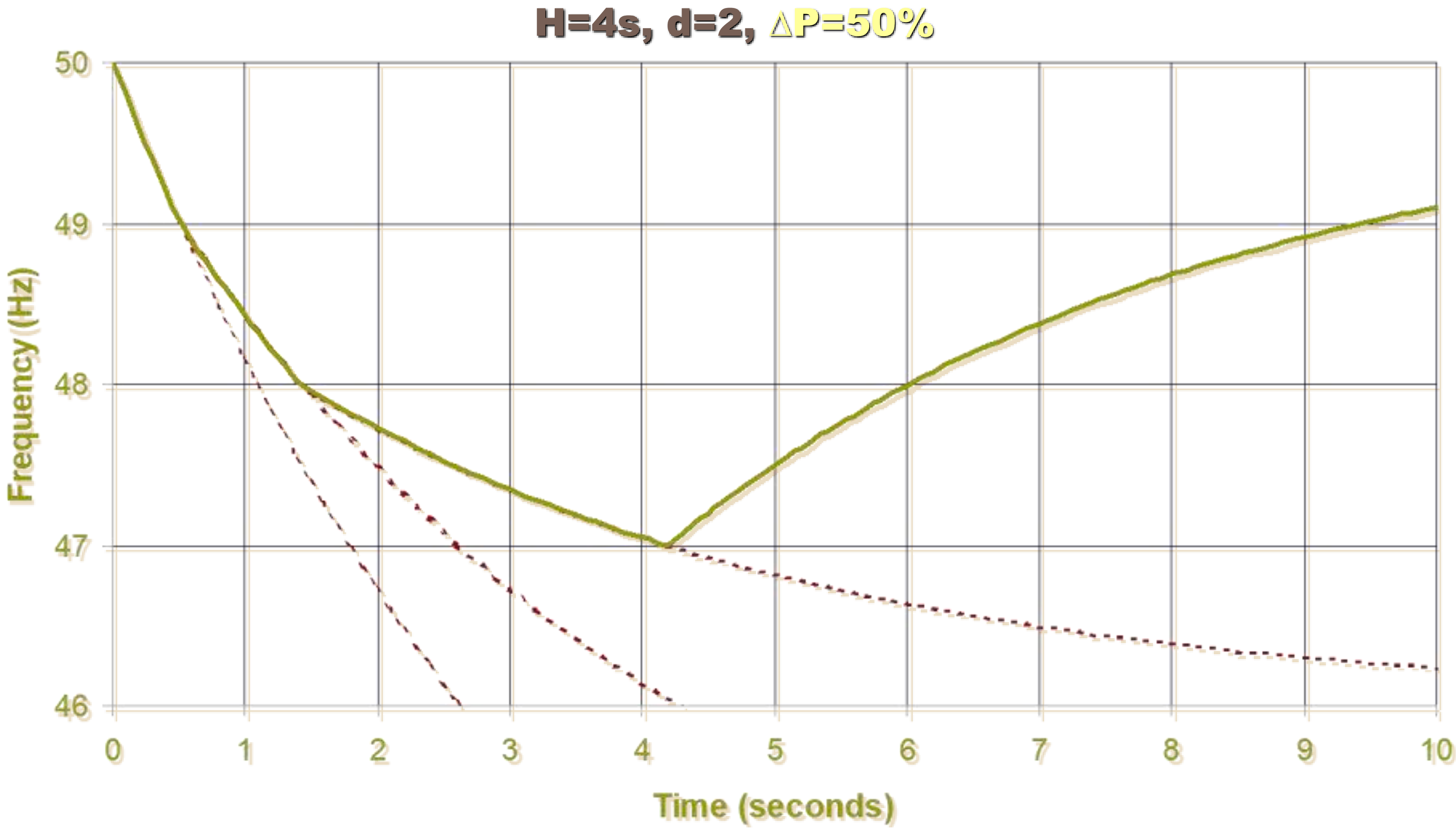
Number and size of shedding stages:

- Many & Small vs. Few & Large
  - Many Small Stages
    - Avoids over-shedding
    - Too slow for large overloads
    - Tends to inhibit system recovery
  - Few Large Stages
    - Over-shedding may occur
    - Faster corrective action for large overloads

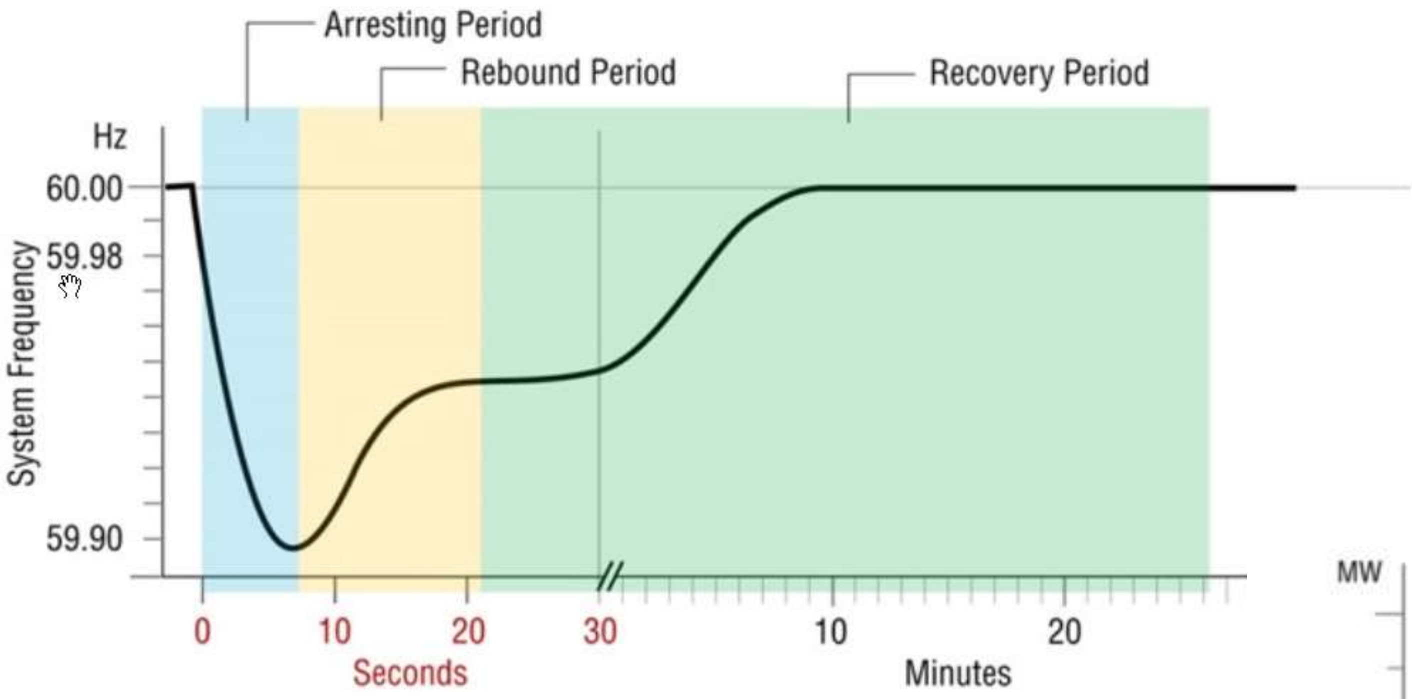
Under-frequency Load Shedding

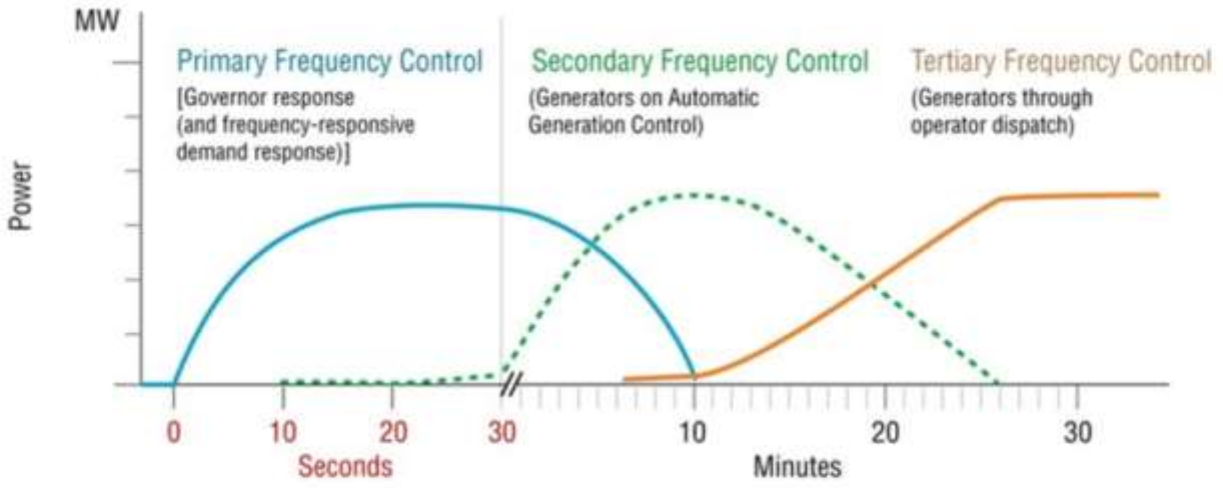


Under-frequency Load Shedding



The Sequential Actions and Impacts on System Frequency of Primary, Secondary, and Tertiary Frequency Control

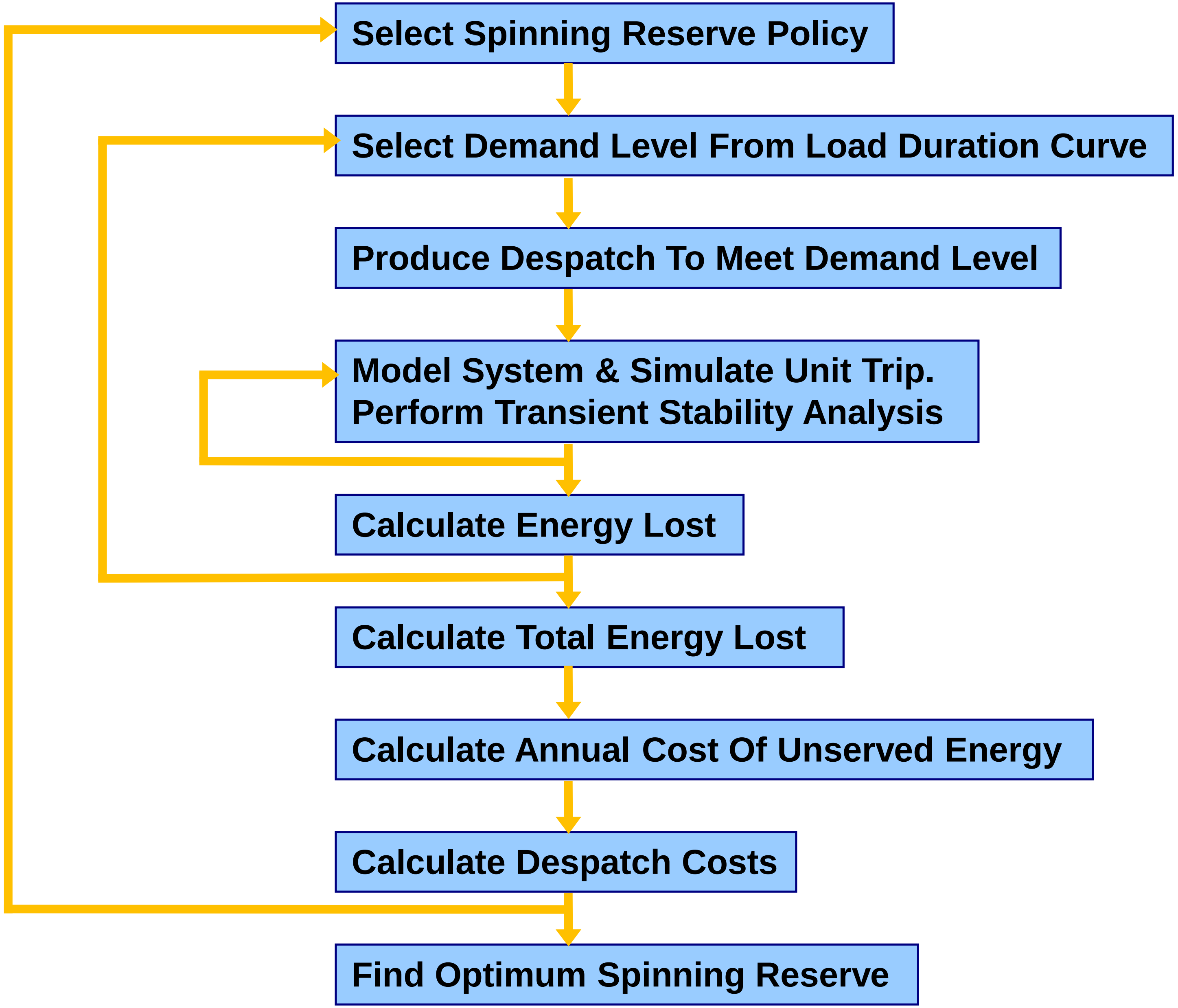




Operational impact

DETERMINING OPTIMUM SPINNING RESERVE

Methodology



Methodology

- Select Spinning Reserve Policy
  - A spinning reserve policy determines the amount of extra capacity of despatched generation over and above the load requirement at any given time.
  - Define several spinning reserve policies for testing.

Methodology

- Select a number of discreet demand levels from the load duration curve
- Produce a generation dispatch for each load level
- For each load level and dispatch, conduct a simulated trip of each of the dispatched generators, using a dynamic computer model
- Obtain the amount of load shed from model, for each generator trip

Methodology

- For each study the amount of load shed will be obtained, and this translated into the value of energy lost:

  Load Shed x Mean Time to Restore Supply x Probability of trip

- The total annual energy lost for each spinning reserve scenario is equal to:

  $\sum$ Energy lost for each load condition x Time condition prevails

Methodology

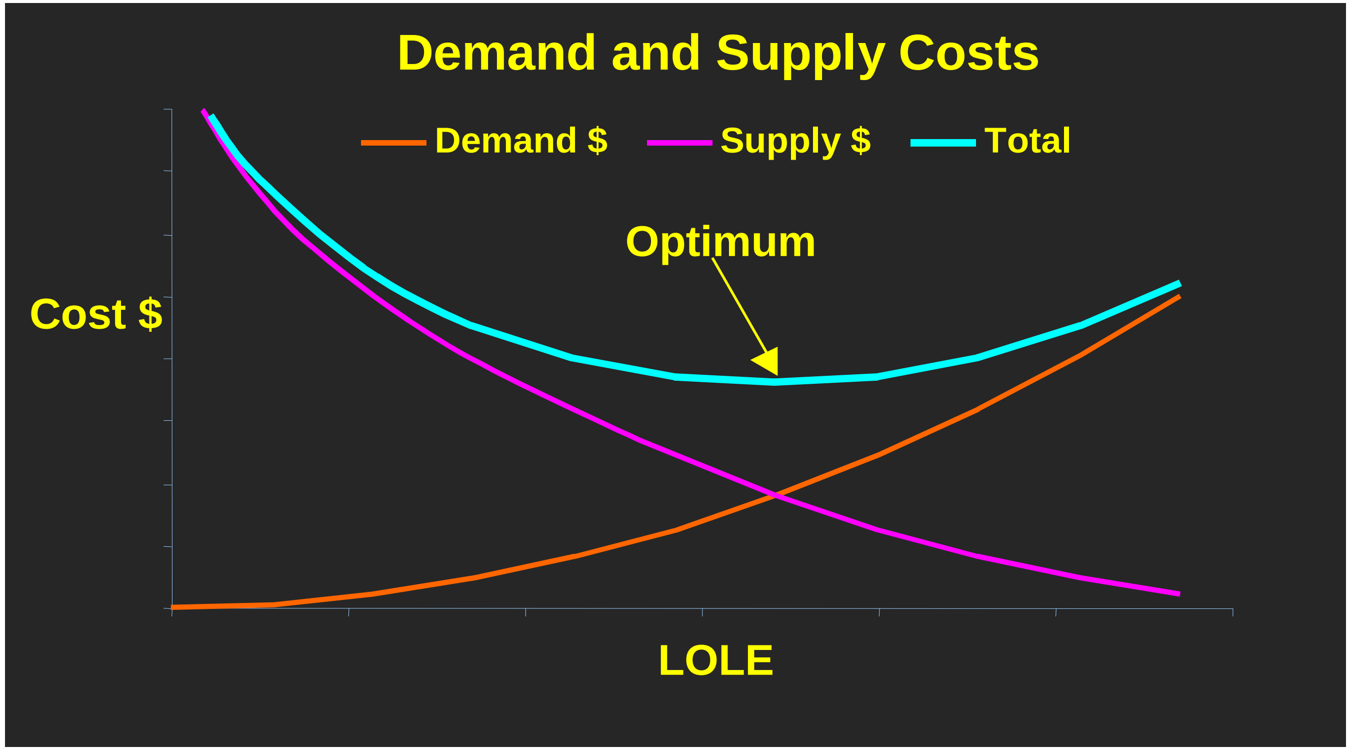
- Calculate the annual cost of unserved energy (COUE) as a result of spinning reserve strategy:

Specific COUE x Total Annual Energy Lost

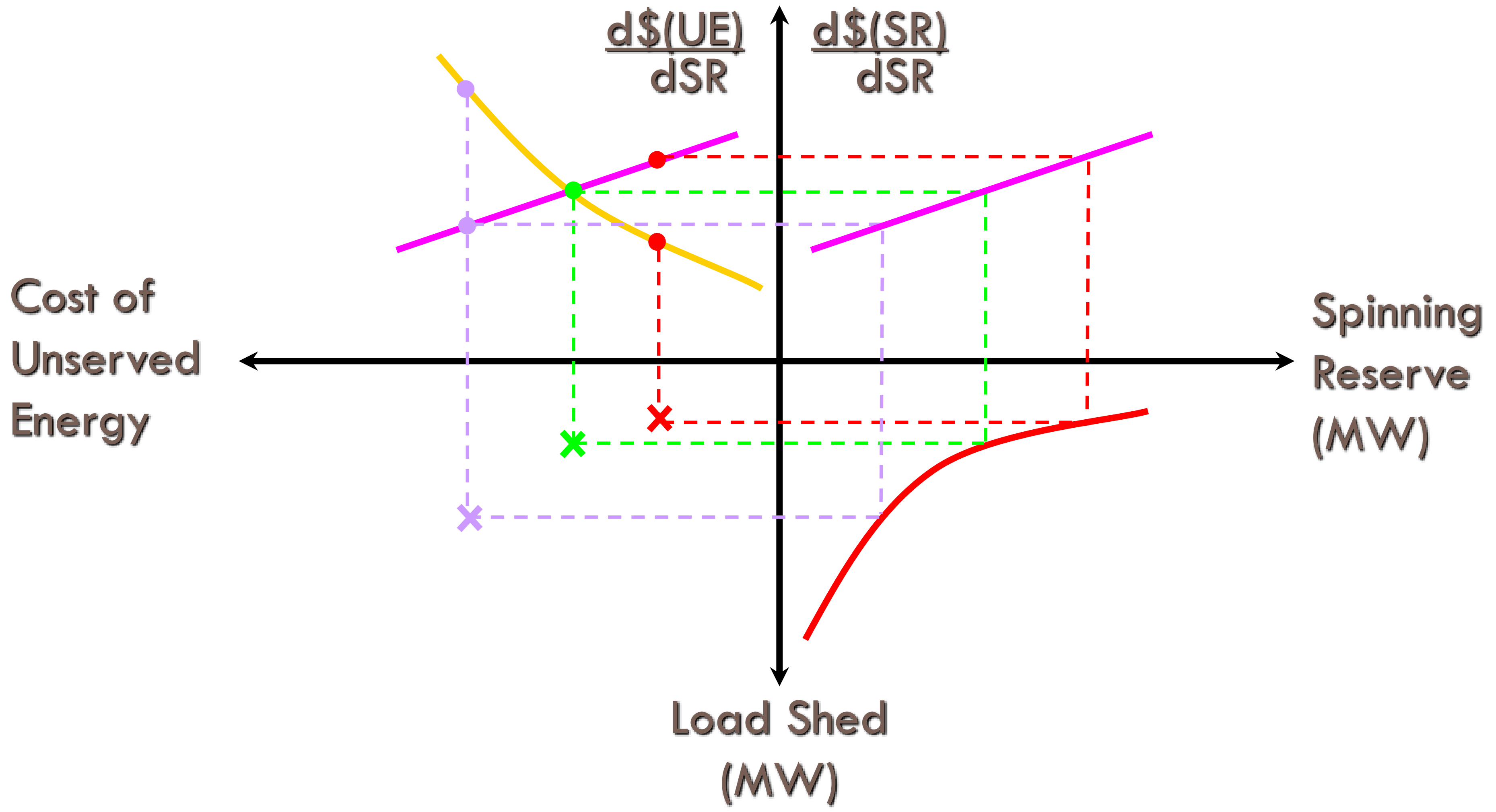
- Calculate the dispatch costs for a given spinning reserve policy, by adding the dispatch costs for various demand levels considered.

Methodology

- Spinning Reserve will be at its economic optimum when the dispatch costs plus the COUE is at its minimum:



Methodology



OPERATING RESERVE REQUIREMENT

Institut Teknologi Bandung

Reserve Margin vs Operating Reserve

- Reserve Margin : Difference between installed capacity of generation with total load.

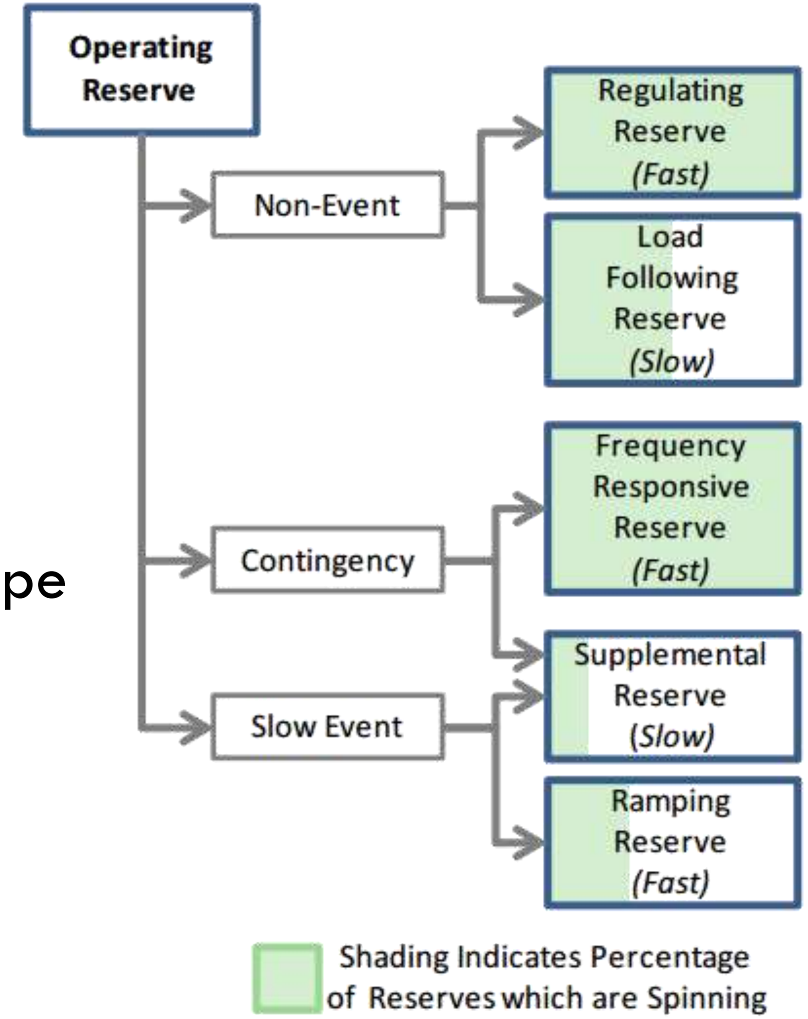
- Operating Reserve : Reserve capacity to maintain system stability between generation and load, when there is a disturbance and/or change in the system (generation lost, load change, etc.)

Type of Operating Reserve

- Based on the type of occurrence
  - Contingency Reserve (initial frequency response against large disturbance)
  - Ramping Reserve (overcome the failure with longer duration: wind forecast error, wind ramps)
- Based on response duration
  - Spinning Reserve
  - Automatic Generation Control - AGC
  - Frequency Responsive Reserve
- Based on supply direction
  - Upward Reserve
  - Downward Reserve

Summary of Operating Reserve Type

- Normal operation:
  - Regulating Reserve (seconds) : spinning
  - Load Following Reserve (minutes) : spinning + non-spinning
- Contingency condition:
  - Frequency Response Reserve (seconds) : spinning
  - Supplemental Reserve (minutes) - reserve for other type of reserve: spinning + non-spinning
- When the failure condition with longer duration:
  - Ramping Reserve (minutes – hours) : spinning + non-spinning



Overview Operating Reserve Type in Europe & US

- US
- Europe
- Spain
- Netherlands
- Denmark
- Ireland
- Quebec

Operating Reserve Type in US

North America Electric Reliability Corporation (NERC)

- Contingency Reserve
- Regulating Reserve (upward & downward)

Operating Reserve Type in Europe

European Network for Transmission System Operators for Electricity (ENTSO-E)

- Primary Reserve
  - Active when frequency deviation 20 mHz
  - Full operation in 30 seconds
  - Share of network
- Secondary Reserve
  - Controlled by AGC dan fast-starting generation
  - Active 30 seconds after disturbance, full operation in 15 minutes
  - Restore the frequency to nominal value
- Tertiary Reserve
  - Restore the reserve level to primary and secondary reserve

Operating Reserve Type in Spain

Spanish Transmission System Operators (TSO) / Red Eléctrica de España (REE)

- Primary Reserve
  - Operated by all generation plant with reserve margin 1.5% for each plant.
- Secondary Reserve
  - Total reserve capacity: +/- 1500 MW
  - Operated by certain generation that is AGC licensed.
- Tertiary Reserve
  - Responsive in 15 minutes
  - Adapt the generation manually to overcome the variation of load and generation.
- Deviation Reserve
  - Overcome the large difference between load and generation (unavailability)

Operating Reserve Type in Netherlands

Dutch Transmission System Operators (TSO) TenneT

- Primary Reserve
  - Share of network ENTSO-E : 670 MW/Hz in 2008
- Secondary Reserve
  - Share of network ENTSO-E : 300 MW in 2008

Operating Reserve Type in Denmark

Nordic Transmission System Operators (Nordel) &
Union for the Co-ordination of Transmission and Electricity (UCTE)

- Primary Reserve
  - Active in seconds-minutes
  - Maximal use for 15 minutes
- Secondary Reserve
  - Dispatched automatically to recover the frequency
  - Generally active for 15 minutes
- Tertiary Reserve
  - Manually recover the reserve level to primary and secondary reserve

Operating Reserve Type in Ireland

- Regulating Reserve
  - Active in 30 seconds
  - Restore the frequency that caused by 0.1 Hz deviation
  - Control inter-system transfer that connected two islands
- Operating Reserve
  - Primary : Active in first 15 seconds, prevent nadir below 49 Hz
  - Secondary : Active up to the next 60 seconds, prevent frequency below 49.5 Hz
  - Tertiary : Active in first 5-20 minutes, restore the reserve level to primary and secondary reserve
- Replacement Reserve
  - Active in first 20 min – 4 hours
  - Restore the reserve level to secondary and tertiary reserve
- Substitute Reserve
  - Active in first 4 – 24 hours
  - Restore the reserve level to replacement reserve

Operating Reserve Type in Quebec

- Stability Reserve
  - 1000 MW, represent 60% lost of one largest generation
- 10-min Reserve
  - 1000 MW, overcome load change, x% lost of one largest generation
- 30-min Reserve
  - 500 MW, represent 50% lost of the second largest generation
- Energy Balancing Reserve
  - 1500 MW day-ahead, 500 MW two hours-ahead, caused by forecast error
- Frequency Regulation Reserve
  - 500 MW (minimal) modulation range with AGC
- Load Following Reserve
  - For load-following, is not determined because there is so many hydropower (43000 MW)

Spinning Reserve Effect to Inertia System

$$H = \frac{-\Delta P_m f_s}{2P_{post,rated}\left(df_s / dt\right)}$$

$$\boxed{H = \frac{-\Delta P_m f_s}{2\left(P_{gen,pre} - \Delta P_m\right) \bullet (1 + SR) \bullet \left(df_s / dt\right)}},$$

Spinning Reserve Effect to Inertia System

$$\Delta P_m = \frac{-2H \bullet P_{gen,pre}(1+SR)(df_s/dt)}{f_s - 2H(1+SR)(df_s/dt)} = \frac{P_{gen,pre} \bullet 2H(1+SR)(df_s/dt)}{2H(1+SR)(df_s/dt) - f_s}.$$

$$\boxed{\Delta P_m = \frac{P_{gen,pre}}{1 - \frac{f_s}{2H(1+SR)(df_s/dt)}}}.$$