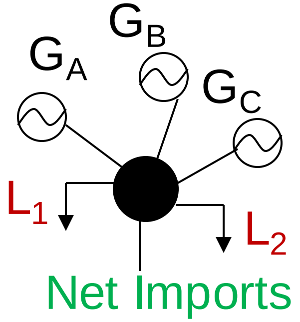
Ancillary Services and Inertia

System Frequency Overview

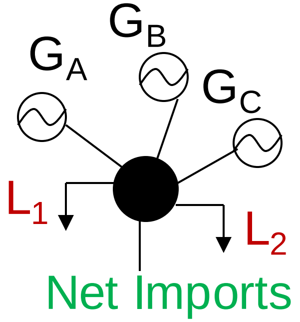
Frequency Deviations

- Infinite bus model assumption
  - Assume all generators, loads, tie-lines are connected to an infinite bus
- Overall net deviation causes frequency deviations



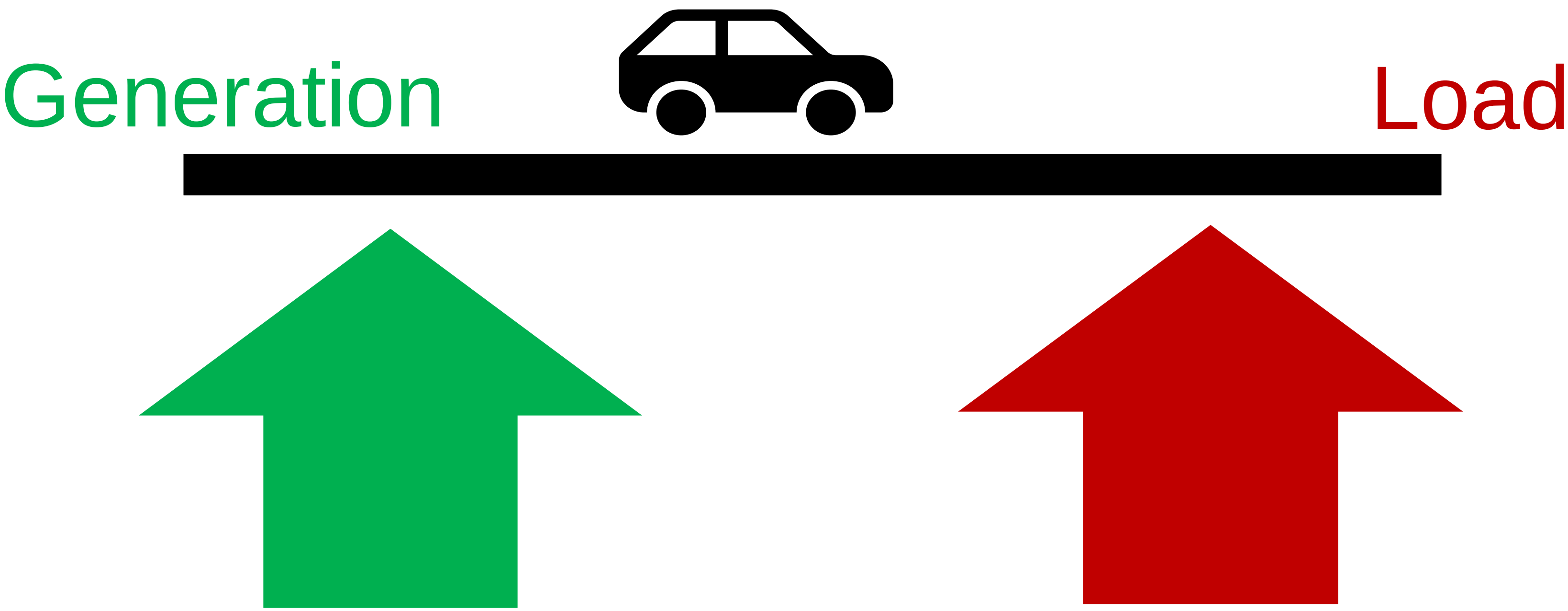
Frequency Deviations

- Total Supply = Total Demand
  - Frequency stays at 60 Hz
- Supply increases beyond Demand or Demand decreases below Supply
  - Frequency increases above 60Hz
- Demand increases beyond Supply or Supply decreases below Demand
  - Frequency decreases below 60Hz



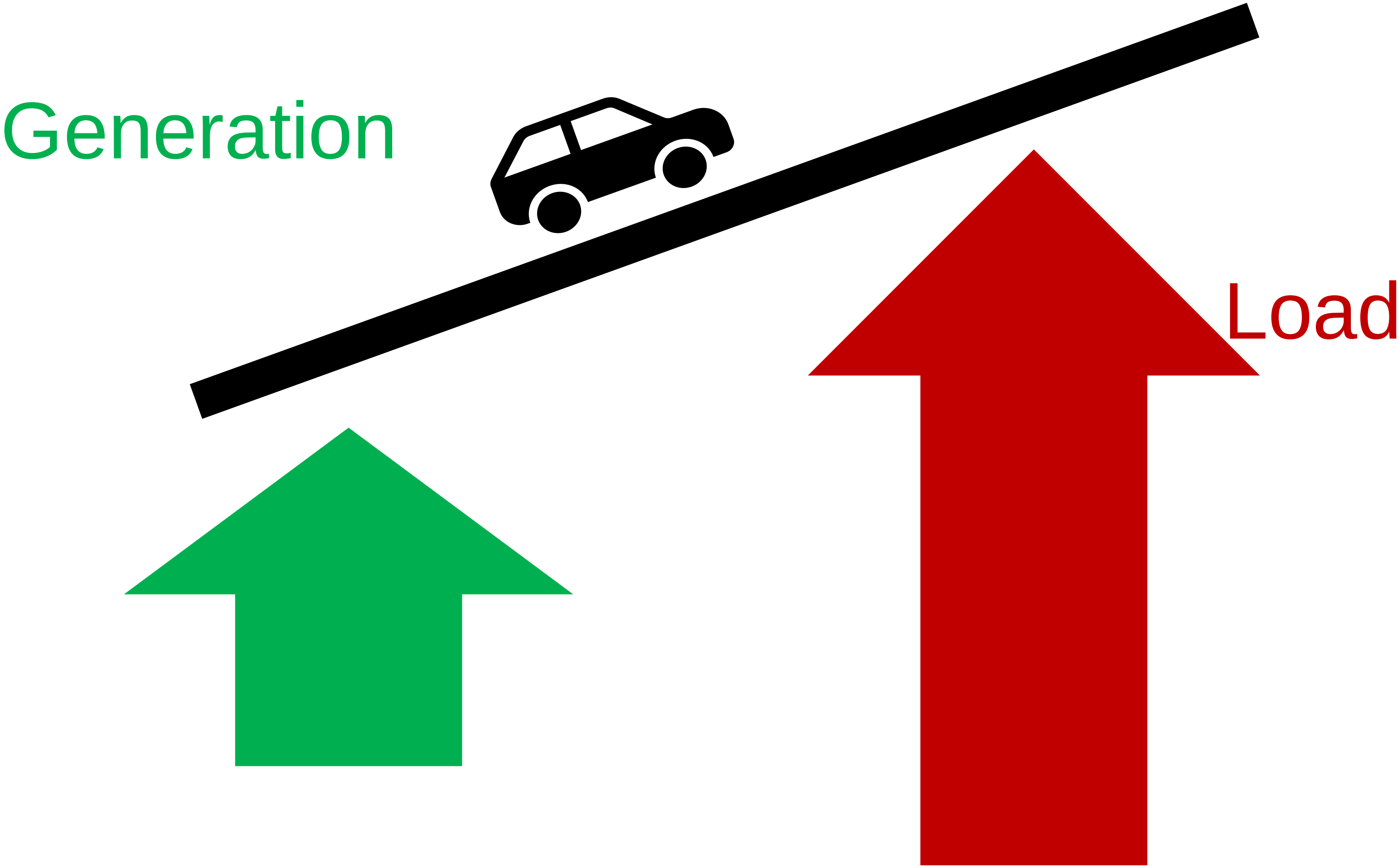
System balanced

Frequency = 60hz

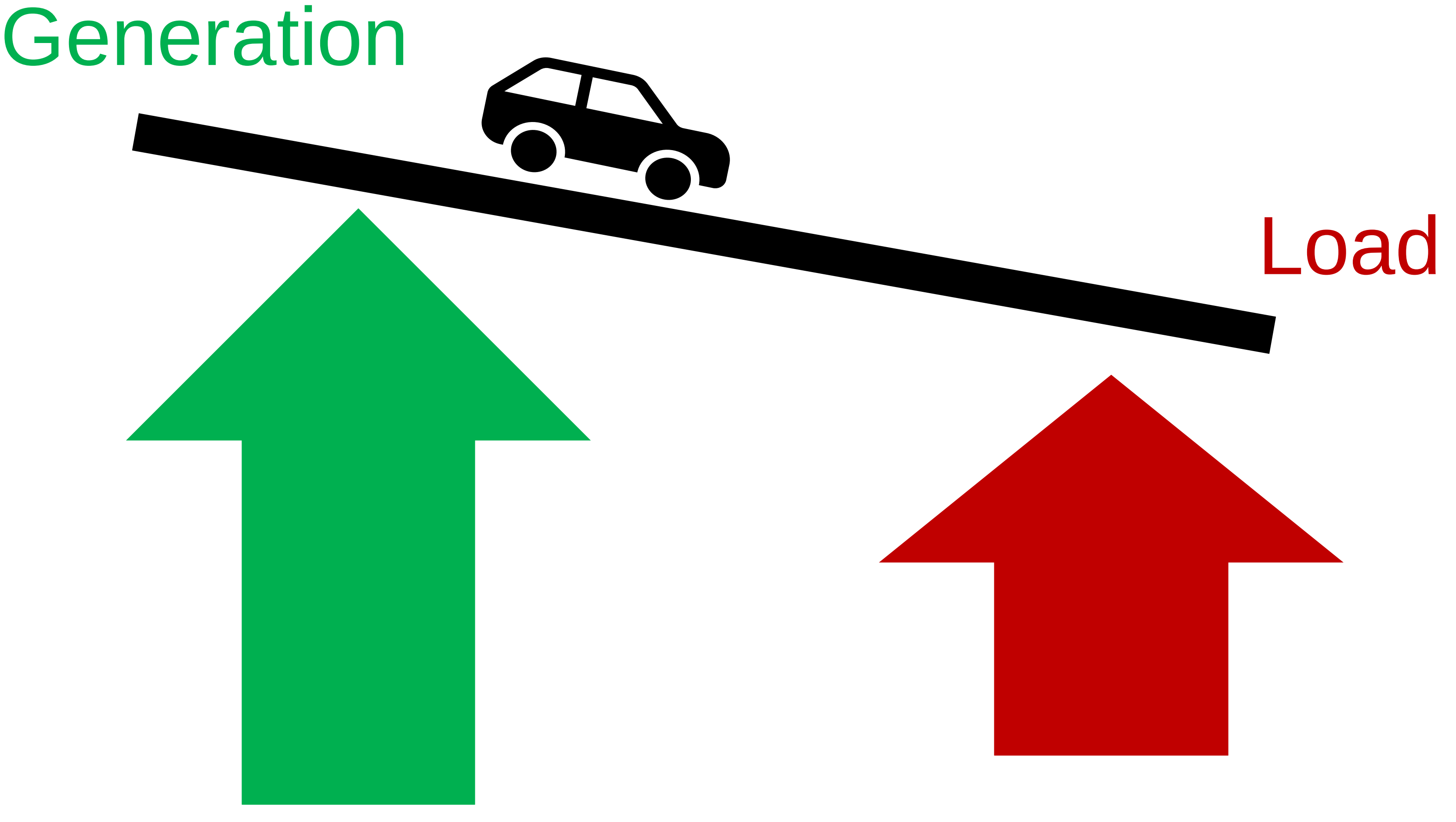


Imbalanced: excess load

Frequency < 60hz



Imbalanced: excess gen
Frequency > 60hz



Frequency Limits

- Generators operate within a tight frequency band
- Generators will trip offline for too low or too high frequency
  (loads may react as well)
- Systems must maintain frequency within a tight operational band to avoid initiating protection systems of assets and additional tripping of units

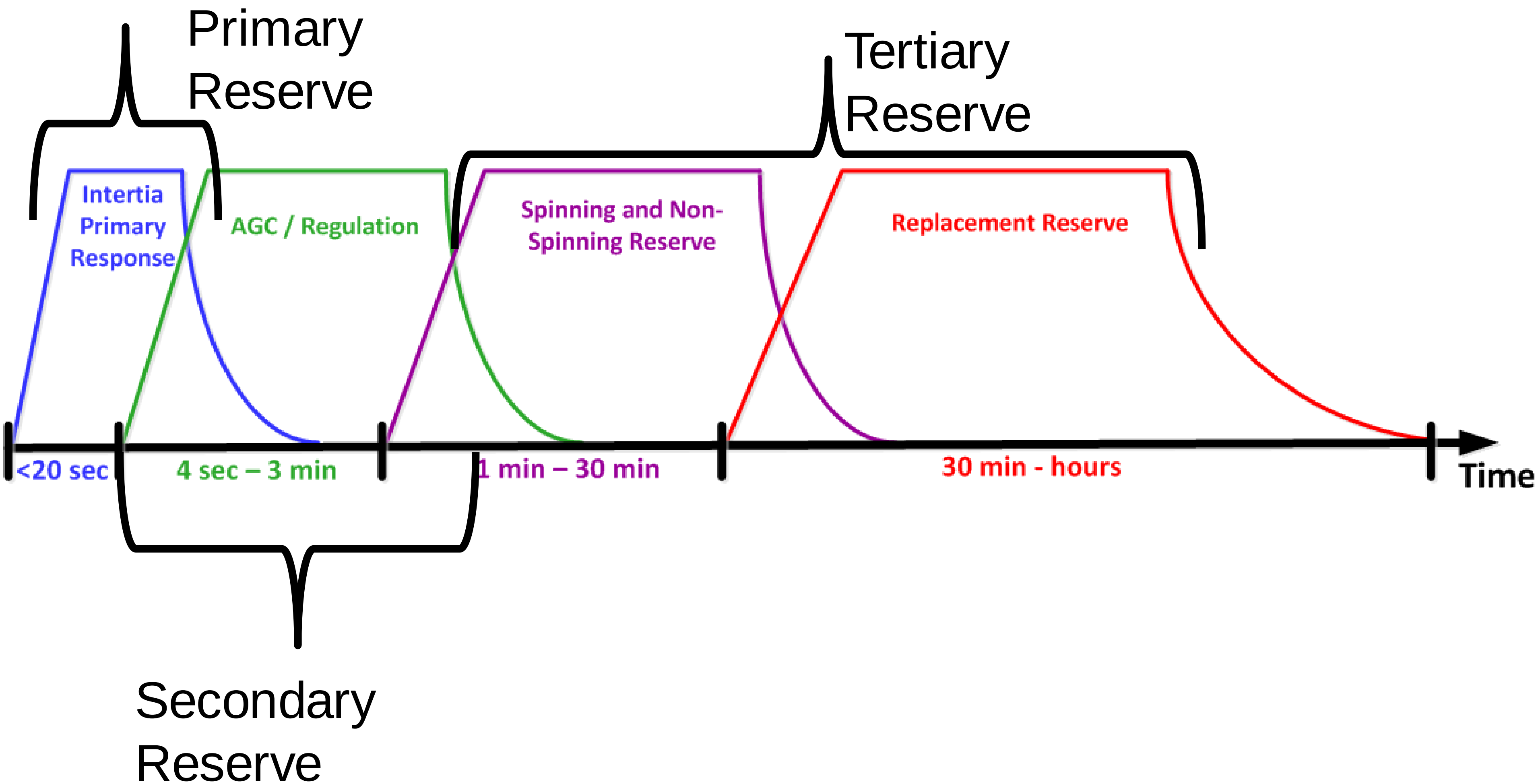
Break

Ancillary Services and Inertia

Overview of
Generator Response and Ancillary Services

Frequency Control Response

What happens when there is a supply/demand imbalance?



Control Responses to Energy Imbalance

Control Response	Response Time	Purpose
Inertia	< 5 seconds	Automatic
Primary control / governor	1- 20 seconds	Automatic
Second control / AGC	4 seconds to 1 minute	Load following
Spinning reserve	< 10 minutes (online gen)	Contingencies, replace AGC (load following) when needed
Non-spinning reserve	< 10 minutes (offline, fast start gen)	Contingencies
Replacement reserve	< 30 minutes	Replace prior reserves in order to regain N-1

Break

Ancillary Services and Inertia

System Response: Reserves

Governor Response (Primary Control)

- Mechanical power being applied to the turbine is adjusted when the shaft speed deviates in speed

- Many variable renewable resources do not have primary control

Automatic Generation Control (Secondary Control)

- Specific units provide regulation reserve (automatic generation control)
  - Natural gas
  - Coal generally does not provide AGC as their response is too slow
- Regulation reserve is used to ensure a supply/demand balance
- Handles small (net) load fluctuations
- Every 4 seconds a signal is sent to the units providing AGC to adjust their output

Spinning and Non-Spinning Reserve (Tertiary Control)

- Operators have different names for these reserves
- Predominant definition and use:
  - 10-minute spinning reserve
    - Contingency based reserve; load following (replace regulation)
    - Online, in sync with the grid
  - 10-minute non-spinning reserve
    - Contingency based reserve
    - Offline, fast-start generators (natural gas)
- Required spinning and non-spinning reserves will be higher with renewable resources
- At this present stage, renewables do not provide such reserves

Replacement Reserve

- Replacement reserve comes on within 30 minutes after a contingency
- Used to replace the higher quality reserves
- Used to help the system get back to an N-1 reliable state
- Purpose: N-1-1: ability to get back to an N-1 secure state after a contingency

Break

Ancillary Services and Inertia

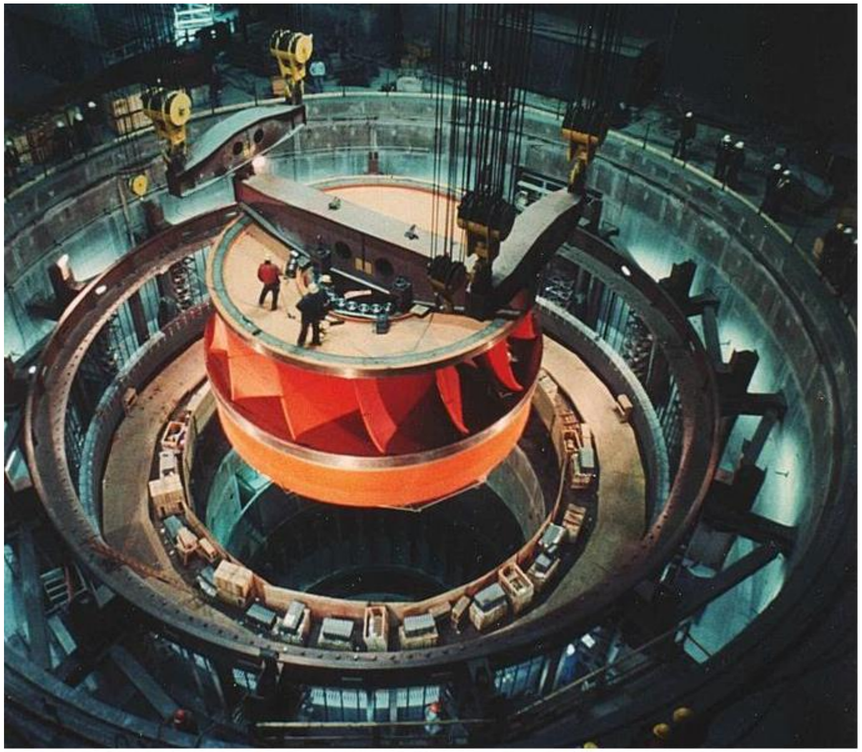
Inertia

The Concern Regarding Inertia

- Large, heavy, rotational generators/turbines have inertia
- The more inertia, the slower the unit will slow down

- Wind provides limited inertia
- Solar PV provides basically zero inertia
- Solar thermal provides some inertia

Turbines and Inertia



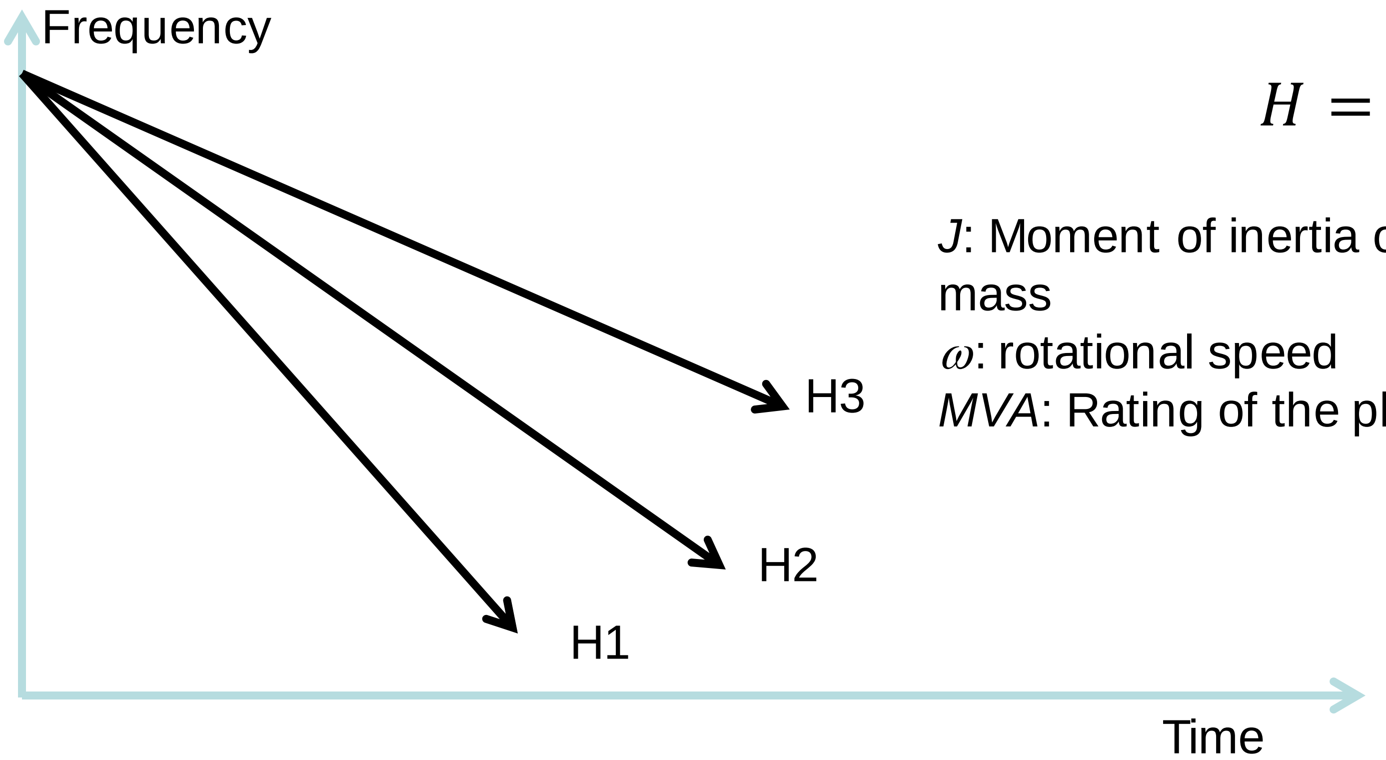
Grand Coulee Dam
Location: Washington State
Total Capacity (multiple turbines): 6800MW
Weight of a Turbine: >100 tons

http://en.wikipedia.org/wiki/File:Water_turbine_grandcoulee.jpg

- Rotational energy makes up for supply demand imbalance
  - Gens slow when excess demand
- Gens trip offline if their speed deviates substantially
  - To prevent damage
- System operators initiate involuntary load shedding (a localized blackout) in order to prevent a full system collapse

Frequency and Inertia

- With less inertia, the frequency will drop faster



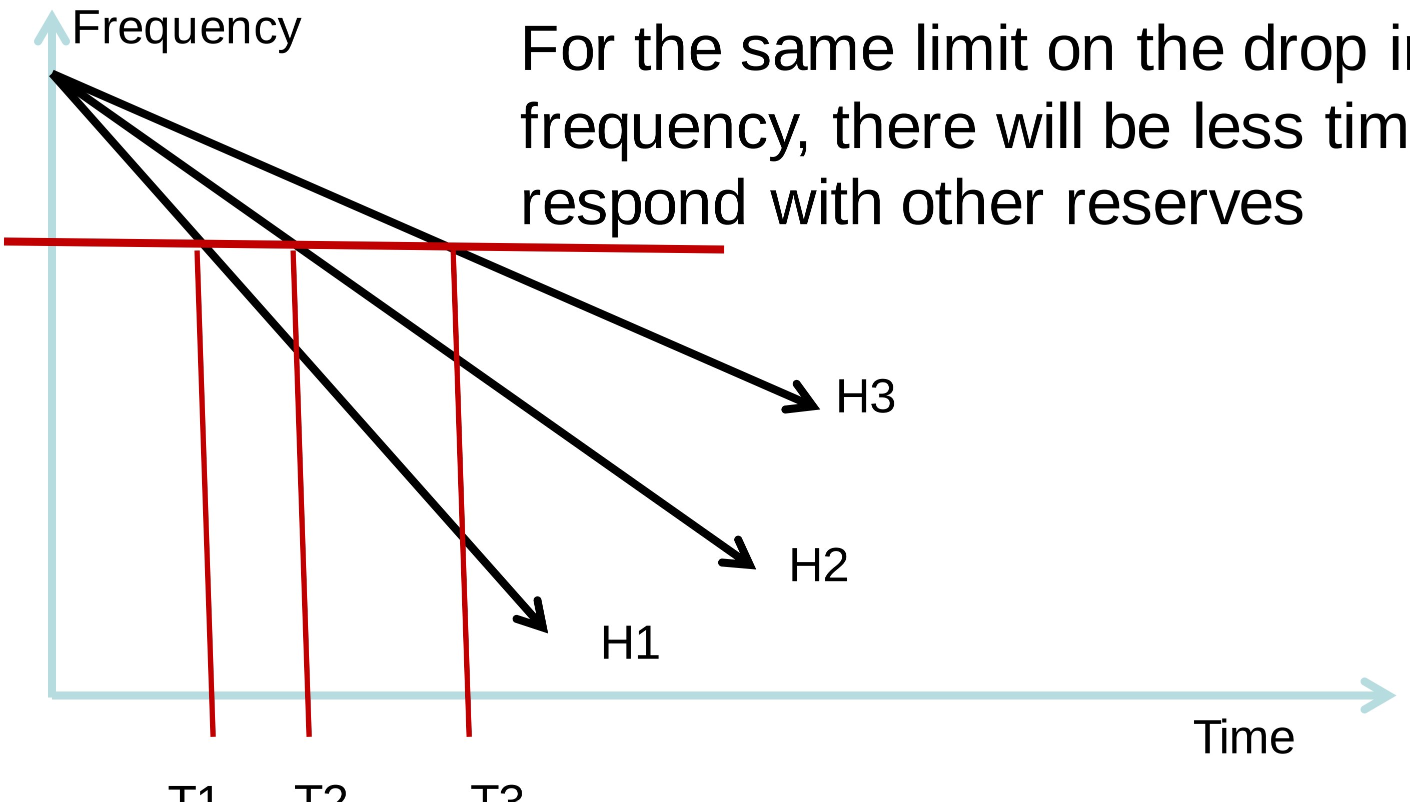
$$H = \frac{\frac{1}{2}J\omega^2}{MVA}$$

J: Moment of inertia of the rotating mass
ω: rotational speed
MVA: Rating of the plant

Frequency and Inertia

- With less inertia, the frequency will drop faster

For the same limit on the drop in frequency, there will be less time to respond with other reserves



Is inertia, by itself, a problem?

- Well, that depends on how you design and operate your system
- Existing operations are designed with the assumption that there is inertia to help us
- We simply need protocols in place to compensate for the lack of inertia
  - Is this possible? Yes
- When there is an event, the inertia of the unit is converted into electric power
  - Rotating mass has stored energy… converted into electrical energy
- All you need to do is to increase the power injection

Break

Ancillary Services and Inertia

Frequency Limitations

Frequency Limitations

Frequency Threshold Values in North America

- Eastern Interconnection: 59.96 – 60.04 Hz
- Western Interconnection: 59.95 – 60.05 Hz
- ERCOT (Texas): 59.90 – 60.10 Hz
- Quebec: 59.85 – 60.15 Hz
- Europe: 49.8 – 50.2 Hz
- Note that the rest of the world does not have such strict limits on the frequency
- Why do we have such limitations in the US?

Frequency Limitations

- Why do we have such limitations in the US?
- Could we allow for a larger deviation to facilitate renewable integration?
- Frequency limitations can impact maintenance
- Frequency limitations must be adopted to ensure damages do not occur to generators
  - Contracts exist covering maintenance and damage to generators relative to operational limits
- Tight restriction: partially a result of contracts
- Limitations are not always technical