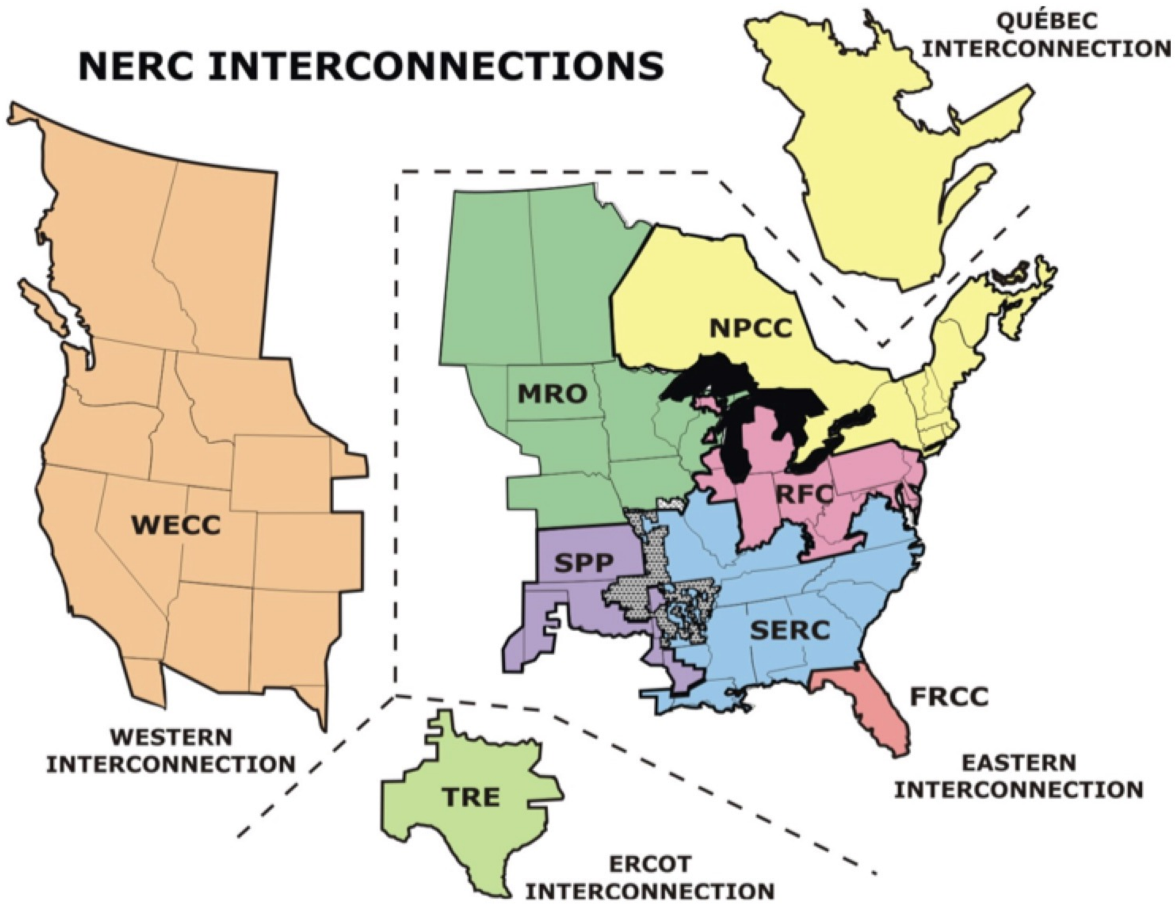
ECE 530: Contemporary Energy Applications

Microgrids

Interconnects and Regional Reliability Coordinators



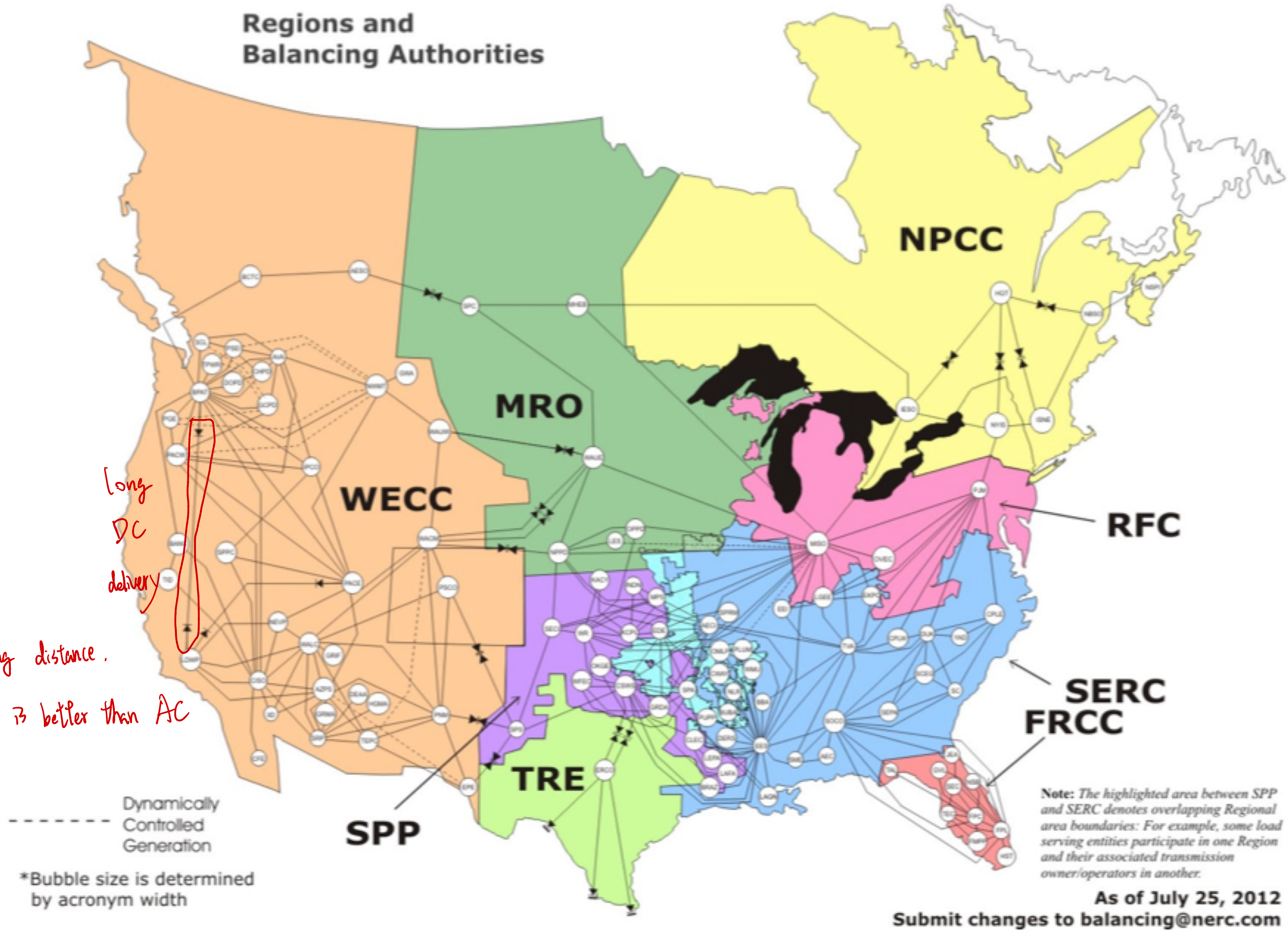
Different Frequencies

- Florida Reliability Coordinating Council (FRCC)
- Midwest Reliability Organization (MRO)
- Northeast Power Coordinating Council (NPCC)
- Reliability First Corporation (RFC)
- SERC Reliability Corporation (SERC)
- Southwest Power Pool (SPP)
- Texas Reliability Entity (TRE)
- Western Electricity Coordinating Council (WECC)

Balancing Areas

Connect two AC grid with different freq

you have to $AC_{f_1} \rightarrow DC \rightarrow AC_{f_2}$

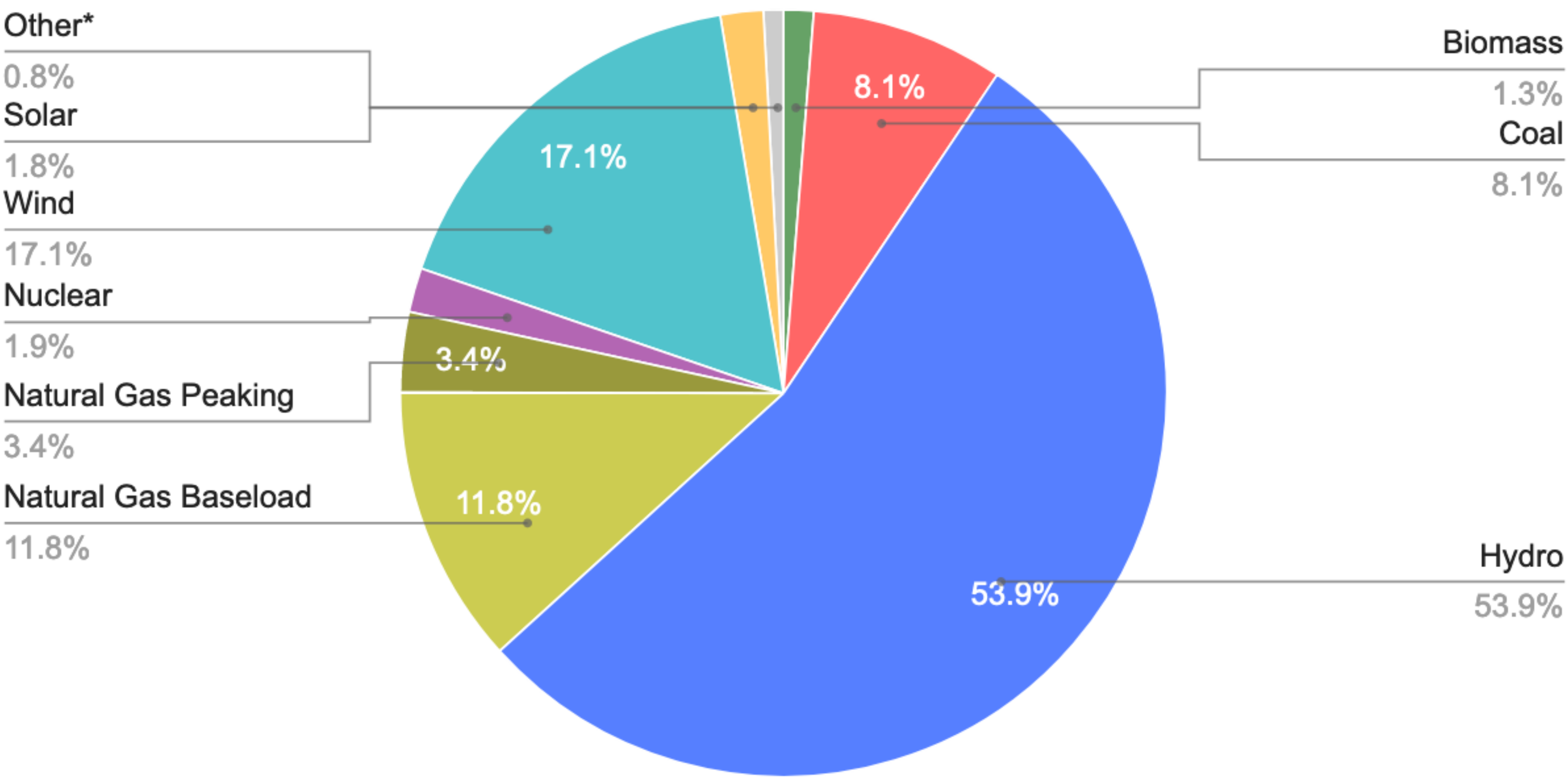


long DC delivery

If long distance, DC is better than AC

PNW Generation Capacity, 2020

Pacific Northwest Generating Capacity: 64,340 mw*

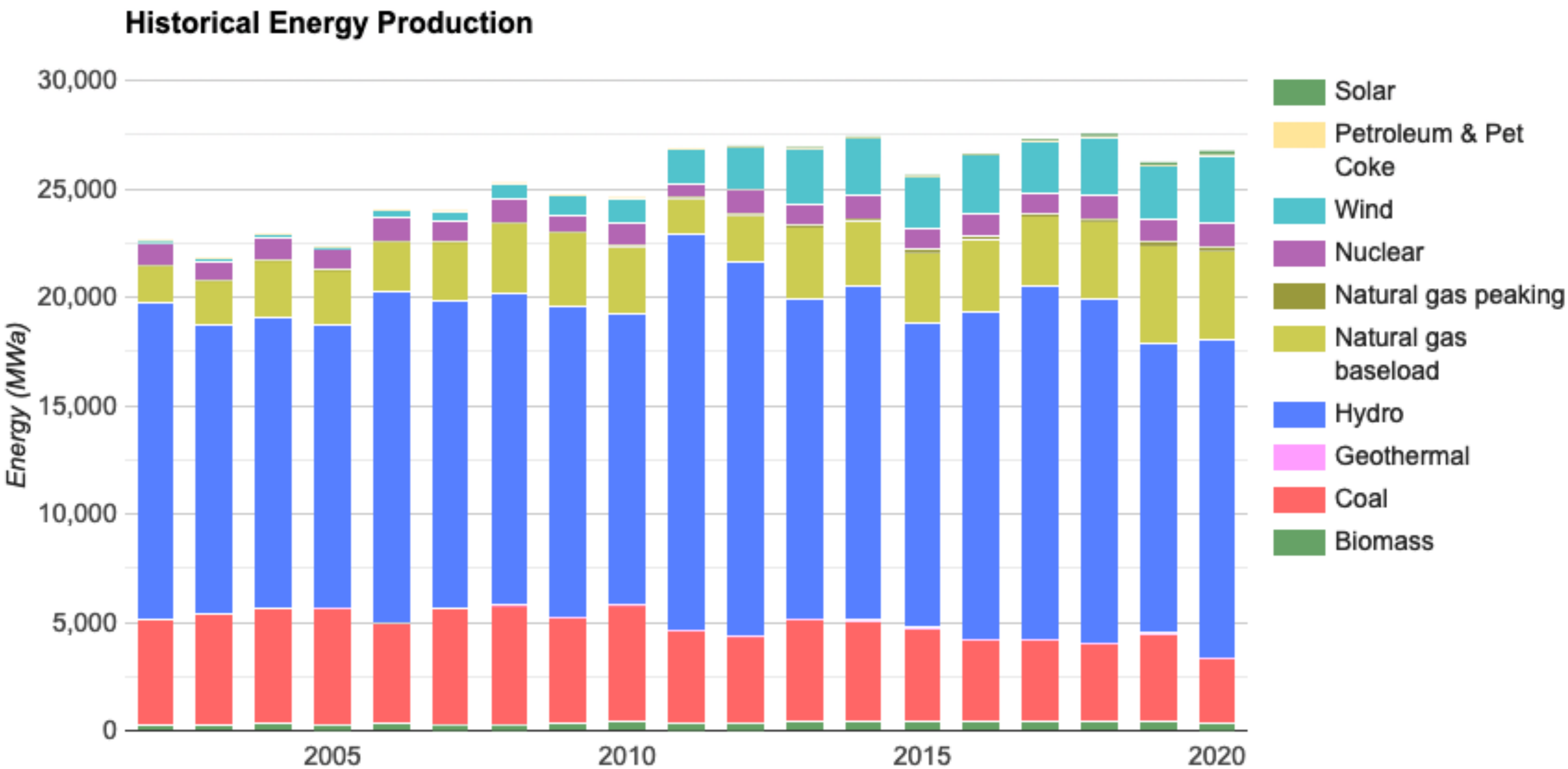


Capacity is essentially the 'horsepower' rating of power plants, or how much they are designed to produce at full load operation. Download chart as PNG

* Other includes geothermal, petroleum, and solar

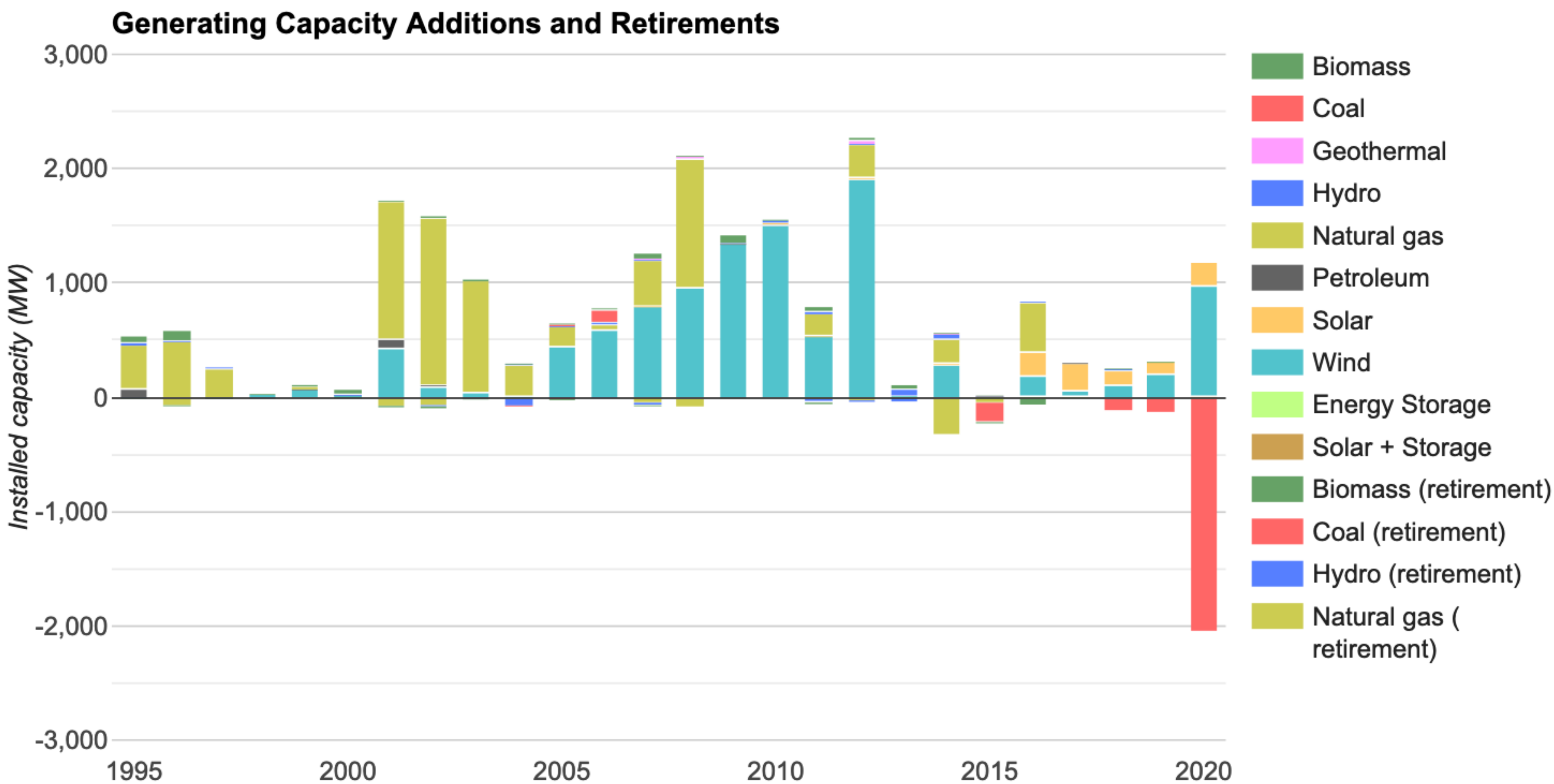
[Northwest Power and Conservation Council]

PNW Production, 2020



[Northwest Power and Conservation Council]

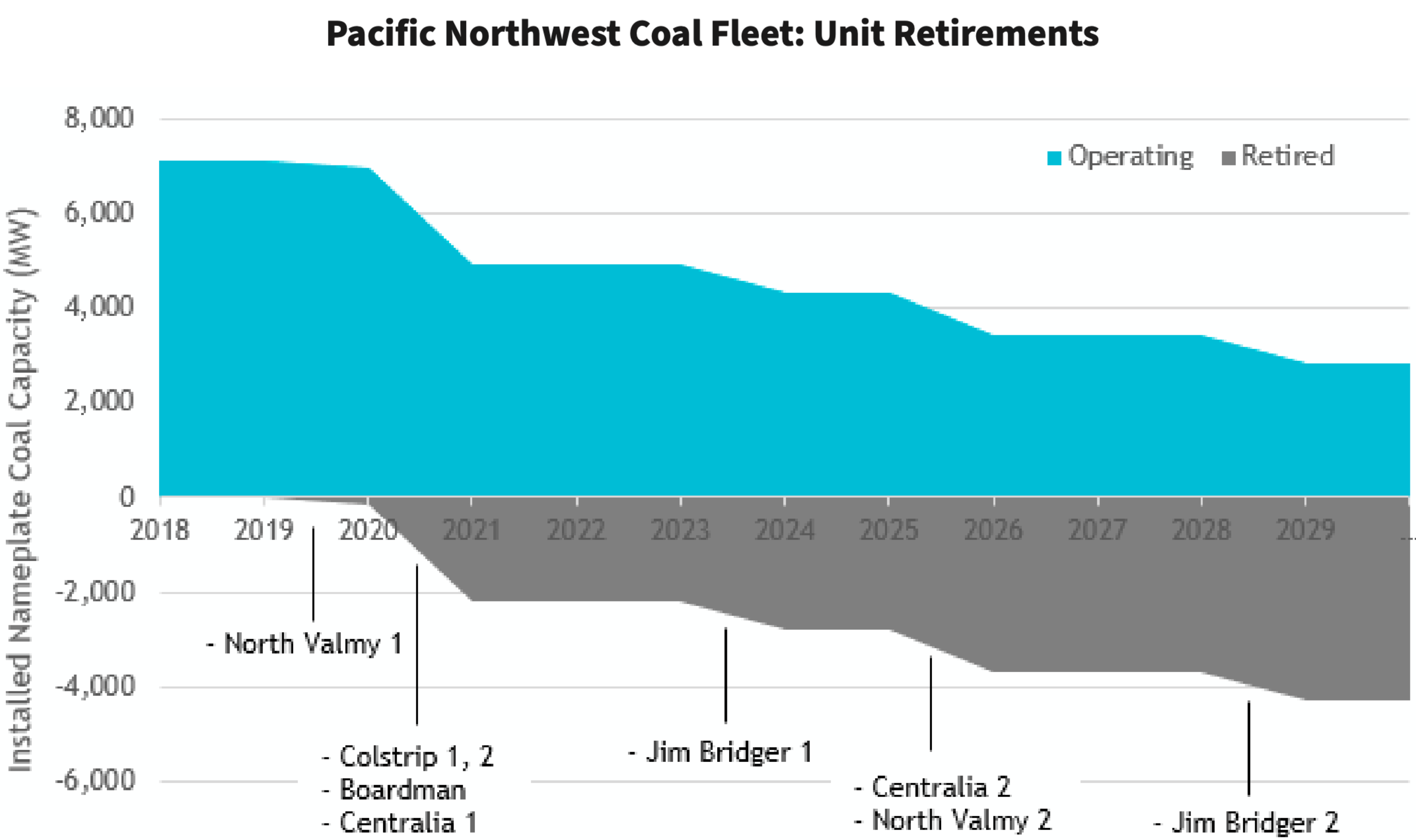
PNW Retirements, 2020



Energy **brought online or retired** each year (new plant construction, etc.). Download chart as PNG

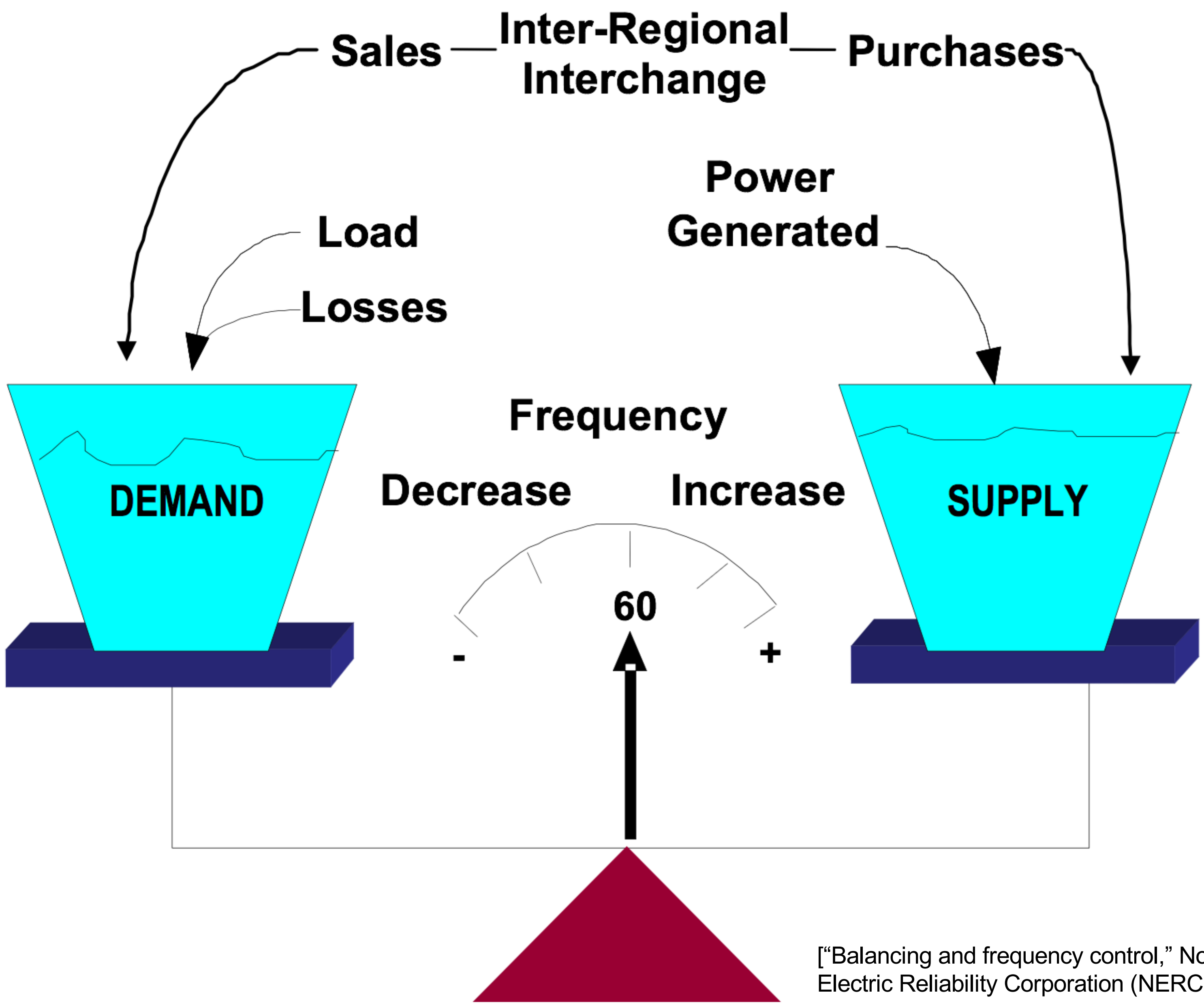
[Northwest Power and Conservation Council]

Coal Retirements



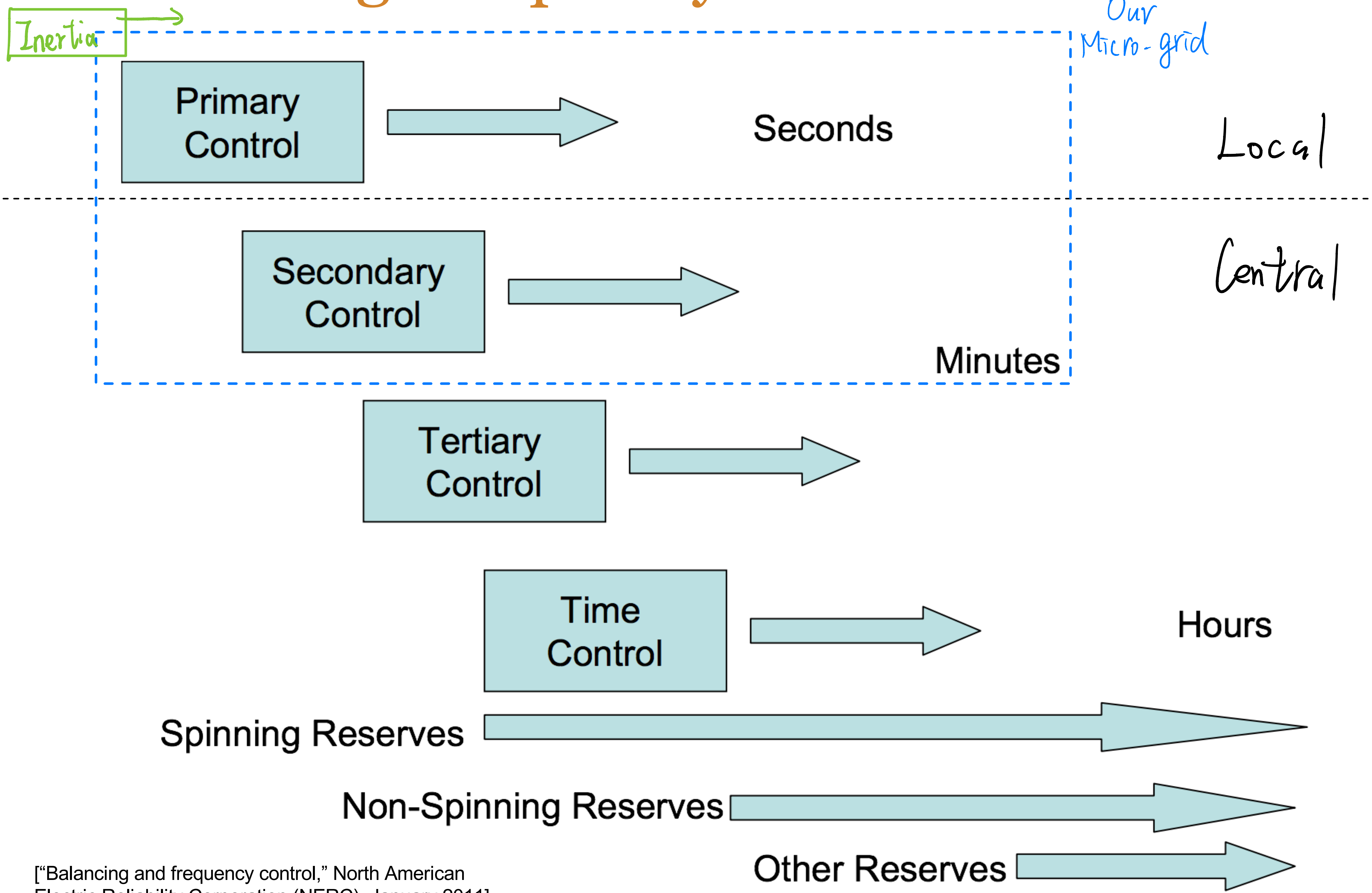
["The 2021 Northwest Power Plan," Northwest Power and Conservation Council]

Interconnect Frequency



["Balancing and frequency control," North American Electric Reliability Corporation (NERC), January 2011]

Controlling Frequency



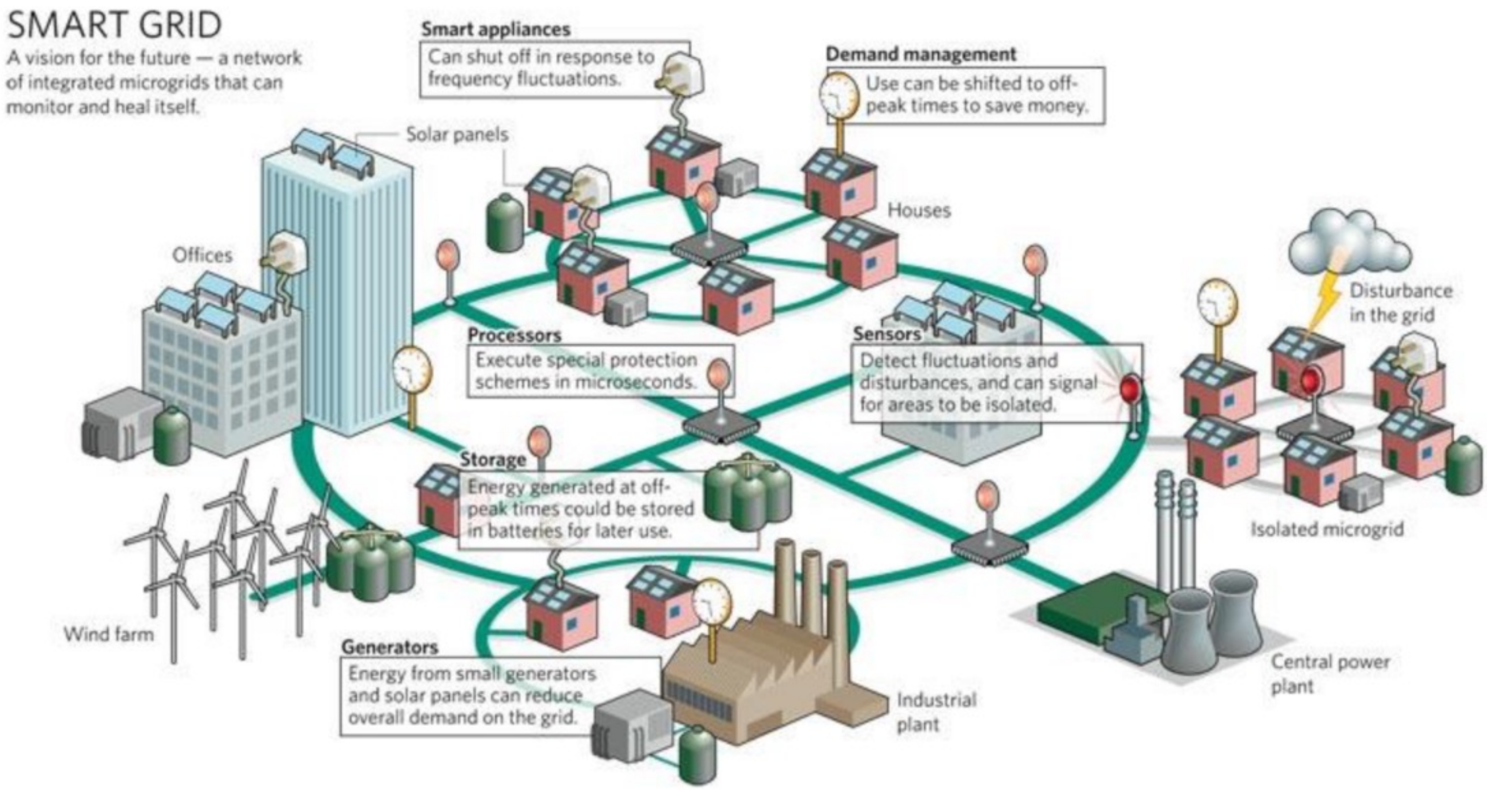
["Balancing and frequency control," North American Electric Reliability Corporation (NERC), January 2011]

Inertia

- Intrinsic energy storage in all rotating machinery connected to the grid.
- Increasing frequency means increasing rotational speed of grid-connected machines, which means energy put into rotational kinetic energy of machines.
- Decreasing grid frequency means decreasing rotational speed of grid-connected machines, which means energy removed from rotational kinetic energy of machines.
- $E = 0.5\, J\omega^2$
- $P = dE/dt = J\omega\; d\omega/dt$

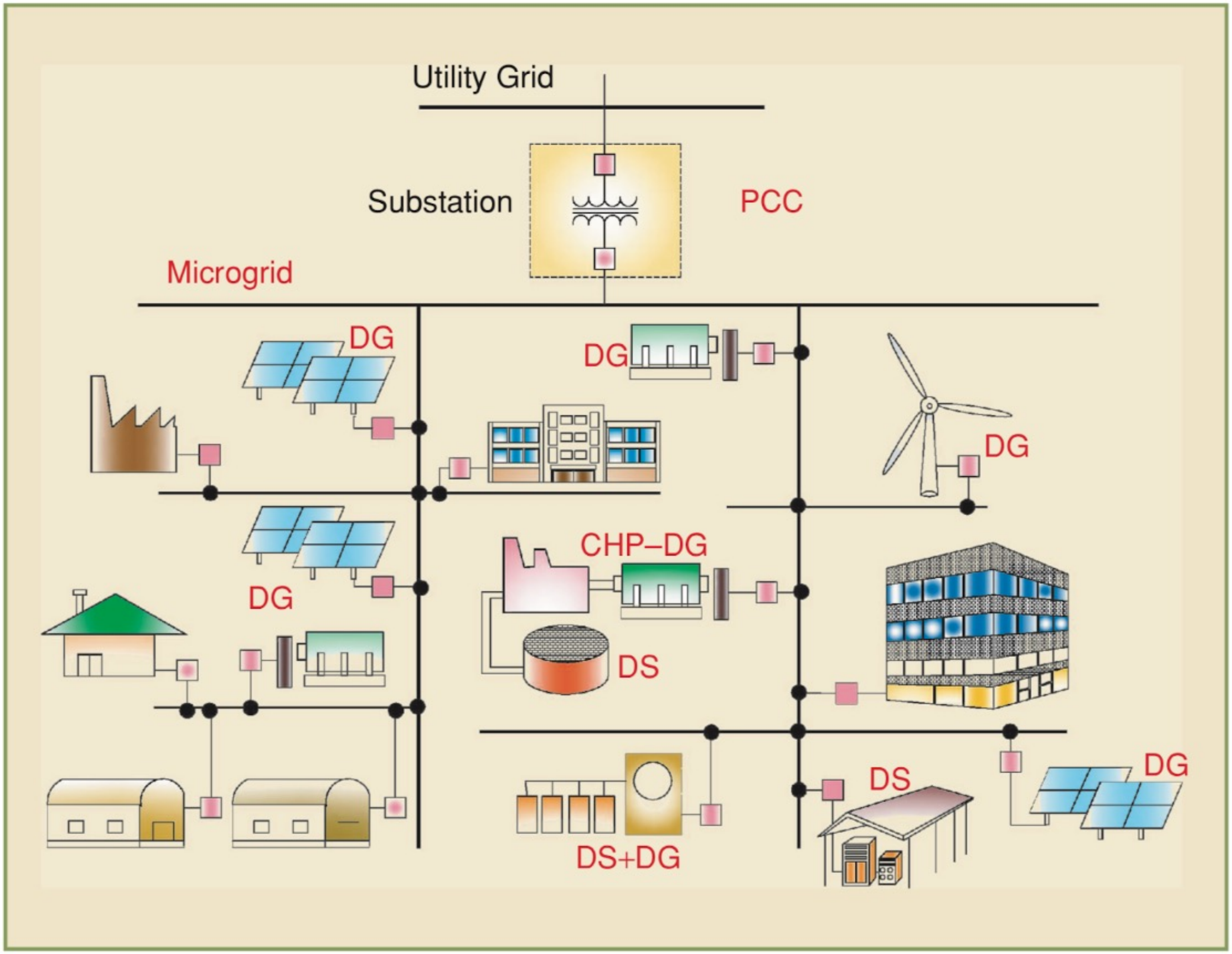
freq $\uparrow$ $\downarrow$ $\qquad$ ω $\downarrow$ $\uparrow$

Smart Grid



- Dispatchable generation (e.g., coal, diesel, etc.)
- Loads with demand response
- Non-dispatchable renewable generation
- Energy storage (stand alone, thermostatic, V2G)
- Synchrophasors for real-time grid monitoring and smart meters for real-time load monitoring
- Automated control of relays, protection schemes Islanding, microgrids

Microgrid



- Some microgrids can operate islanded or grid-connected

Microgrid

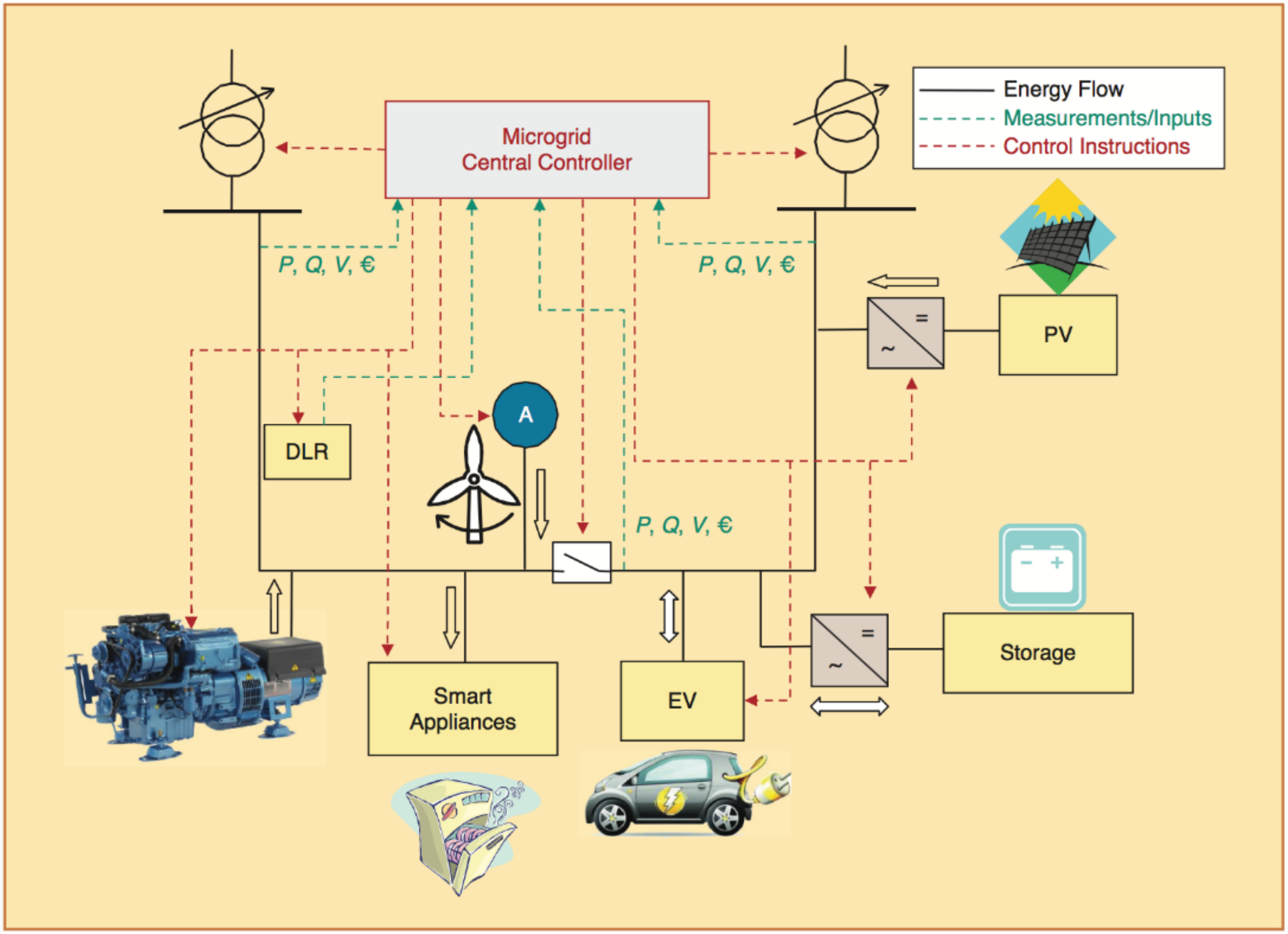


figure 3. An overview of a microgrid physical architecture.

- Local control can be used for voltage and frequency control.
- Centralized control can be used for energy dispatch and other stability functions.

Sendai Hills Microgrid Performance

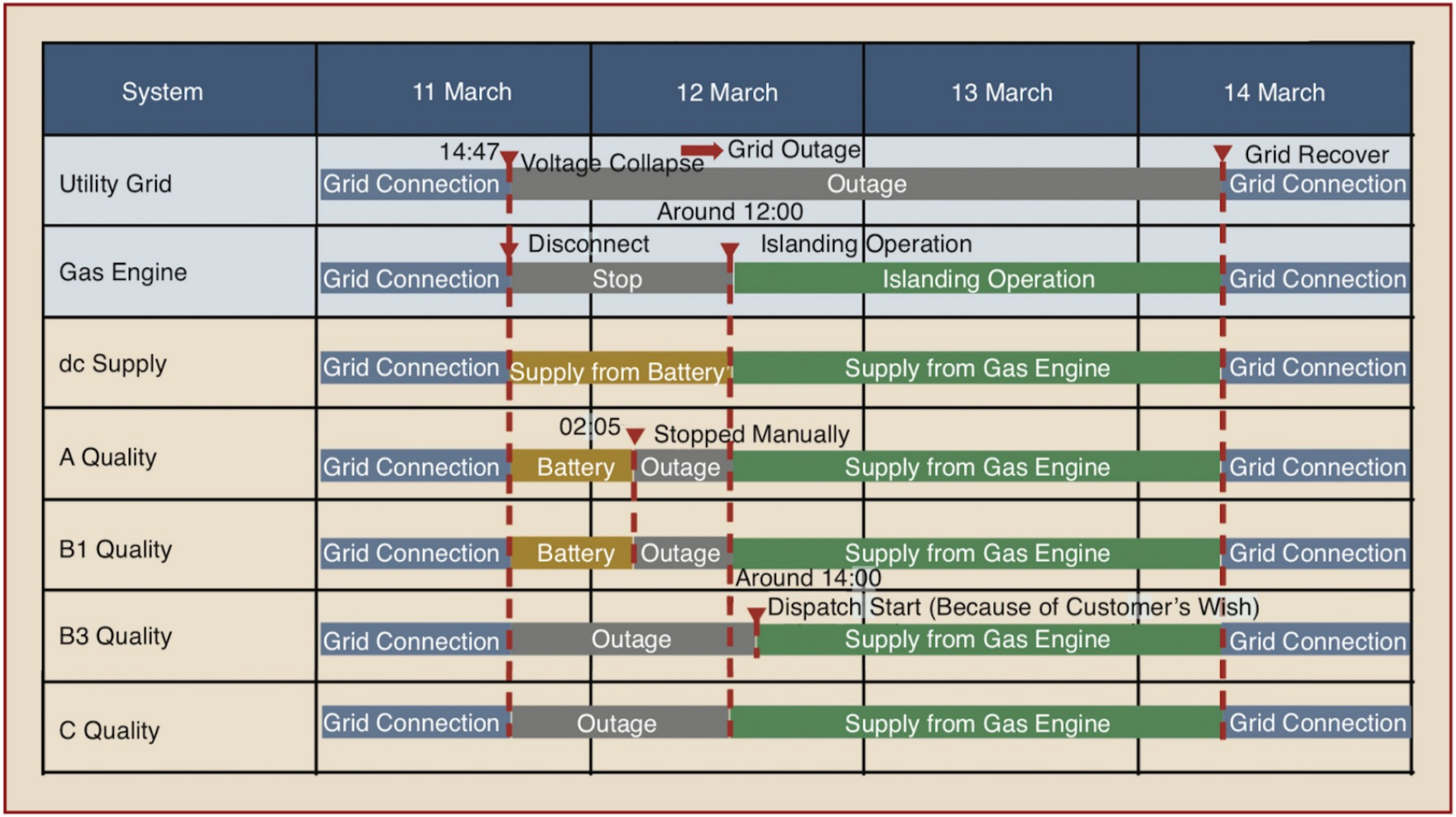


figure 13. The operation of the SM during the GEJE. (Source: NTT Facilities.)

C. Marnay, et al, "Japan's Pivot to Resilience," *IEEE Power and Energy Magazine*, May/June 2015

Inertia Modeling

- H is the seconds amount of power stored in the rotating mass at the rated power.

e.g. $P_{base} = 1\,MW$

$P_{gen} = 750\,kW$

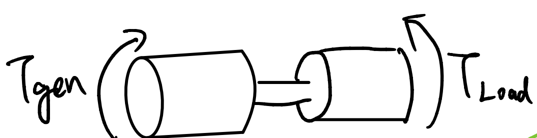
$$P_{gen,pu} = \frac{750kW}{1MW} = 0.75\ pu$$

$$E = \frac{1}{2} J W^2$$

hard to get/measure

The base of per unit

$$\frac{\frac{1}{2} J W^2}{P_{rated}} \quad \frac{[J]}{[W = J/s]} = H\ [s] = \frac{\frac{1}{2} J W_{base}^2}{P_{base}}$$



$$P = T \cdot W \rightarrow \frac{P_{base}}{W_{base}} = T_{base}$$

$$T_g - T_L = J \frac{\partial W}{\partial t} = 2 \cdot \frac{P_{base}}{W_{base}^2} \cdot H \cdot \frac{\partial W}{\partial t} = 2 \cdot \frac{T_{base}}{W_{base}} \cdot H \cdot \frac{\partial W}{\partial t}$$

$$\rightarrow \frac{T_g - T_L}{T_{base}} = T_{g,pu} - T_{L,pu} = \underbrace{2H}_{M} \cdot \frac{\partial W_{pu}}{\partial t}$$

Inertia, Power, and Frequency

- We need to model frequency in terms of power balance (generation and load).

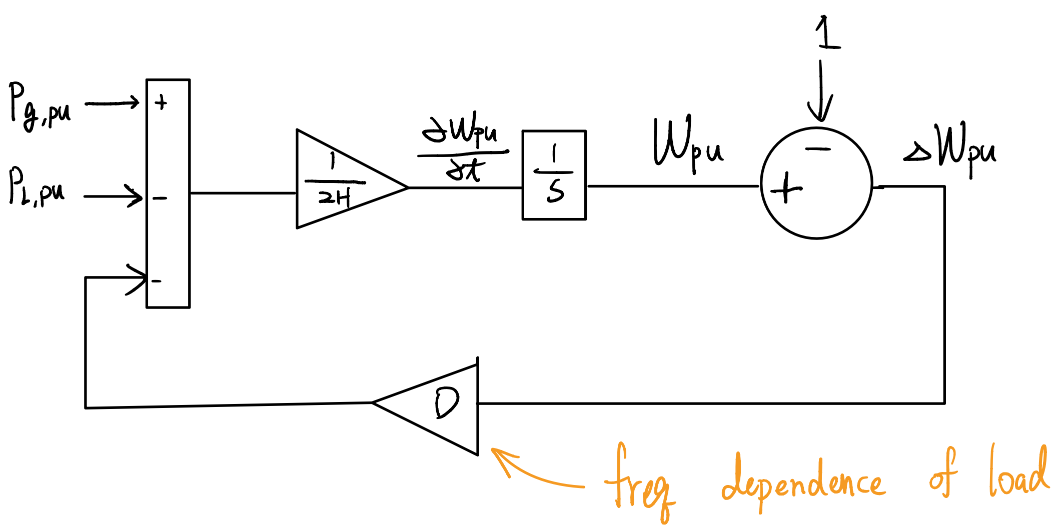
$$2 \cdot H \cdot \frac{\partial W_{pu}}{\partial t} = T_{g.pu} - T_{L,pu}$$

$\times W_{pu}$ $\qquad$ $\times W_{pu}$

tricky

$$\approx 2 \cdot H \cdot \frac{\partial W_{pu}}{\partial t} = P_{g,pu} - P_{L.pu}$$

$$\rightarrow \frac{\partial W_{pu}}{\partial t} = \frac{1}{2H}\left(P_{g,pu} - P_{L,pu}\right)$$



Wind turbine → Inertia → AC → DC → Grid

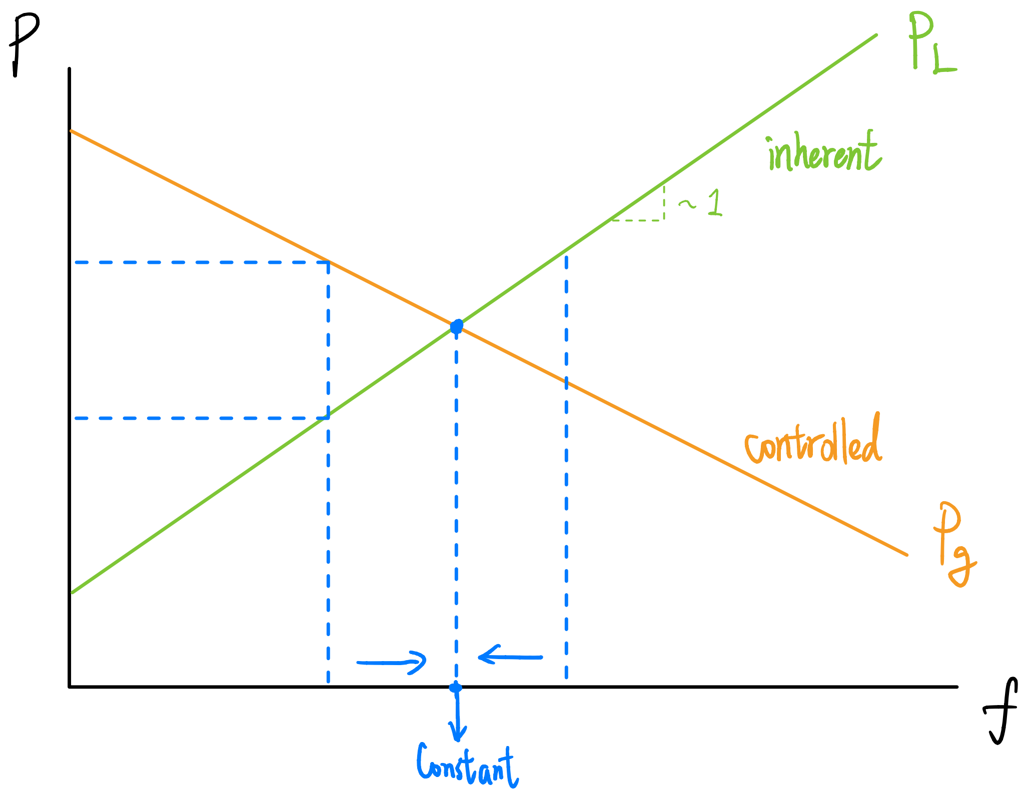
Not direct connection to grid

Frequency Stability

inherent

- The motor component of the aggregate load has a positive frequency dependence. In general, if the frequency decreases, the load decreases, and vice versa.
- Generation is generally controlled to have the complimentary frequency dependence: when the frequency decreases, the generation increases. This is not an inherent characteristic of the generation, it is actively controlled.
- These two behaviors combined tend to stabilize the grid frequency.

$$\begin{cases} f\downarrow : P_g\uparrow, \\ f\uparrow : P_g\downarrow \end{cases}$$



Primary and Secondary Control

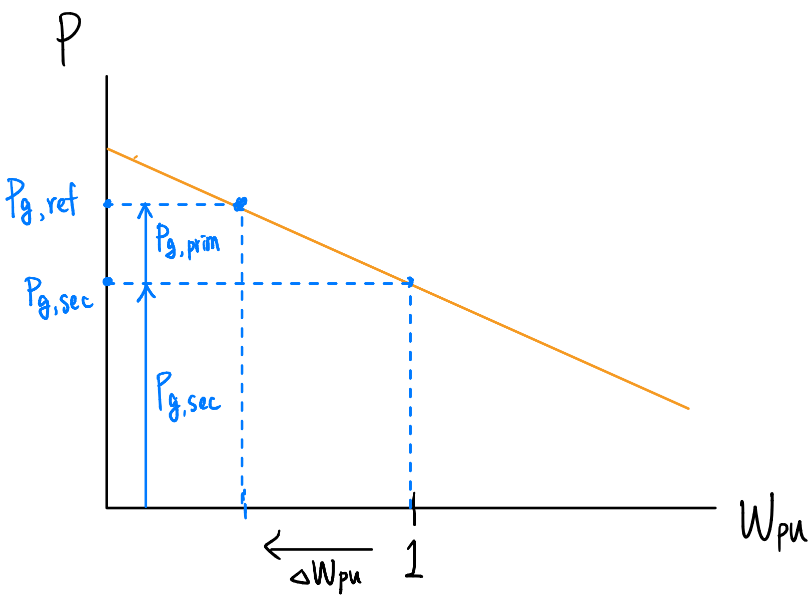
2nd + 1st

- The generator control reference is the sum of a secondary signal and a primary signal.
- The secondary signal is dispatched to the generator from a centralized controller.
- The primary signal is frequency dependent and is locally generated. It causes the generator to produce more or less power than dispatched, in response to the frequency.
- Speaking simply, all loads and generators see the same frequency within a grid.

Primary Control : Local

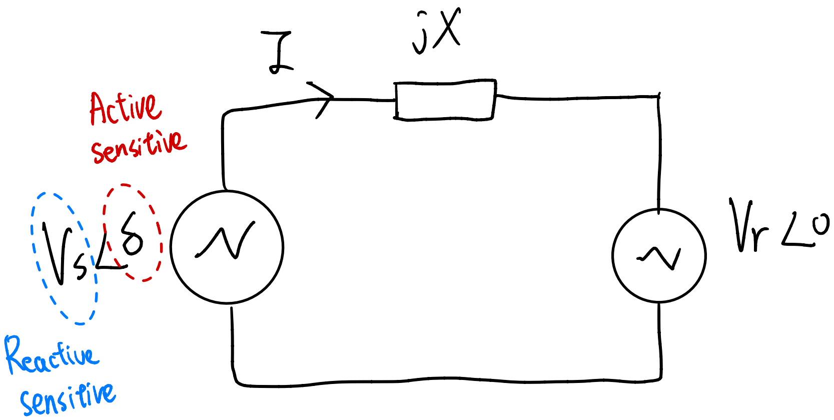
Secondary Control : Centralized

$$P_{g,ref} = P_{g,prim} + P_{g,sec} = \overbrace{\underbrace{-K_{g,prim}}_{=20} \cdot \Delta W}^{P_{g,prim}} + P_{g,sec}$$



Two Bus Power Flow

- Active power flow (and thus frequency) has a strong relationship to voltage angle.
- Reactive power flow has a strong relationship to voltage magnitude.



$$I = \frac{V_s\angle\delta - V_r\angle 0}{jX}$$

Reactive Power

$$S_s = \underset{[W]}{P_s} + j\cdot \underset{[VAR]}{Q_s} = (V_s\angle\delta)\cdot I^*$$

$$= (V_s\angle\delta)\left(\frac{j\cdot V_s\angle-\delta - j\cdot V_s}{X}\right)$$

$$= \frac{j\cdot V_s^2\angle 0 - j\cdot V_r V_s[\cos(\delta) + \sin(\delta)]}{X}$$

$$= \underbrace{\frac{V_r\cdot V_s\cdot \sin(\delta)}{X}}_{W} + j\cdot \underbrace{\frac{V_s^2 - V_r V_s\cdot\cos(\delta)}{X}}_{Q}$$

$$V_s\angle\delta = V_s e^{j\delta}$$

$$e^{j\delta} = \cos(\delta) + j\cdot\sin(\delta)$$

$$e^{j\pi} = \cos(\pi) + j\cdot\sin(\pi)$$

$$e^{j\pi} + 1 = 0$$

Microgrid Control

- A power dispatch control algorithm sets the generation power set point (secondary command). The setpoint power is further adjusted by primary control (which is done locally).
- Reactive power is controlled based on the voltage magnitude at the point of generator coupling.