Power System Long-Term Dynamic Simulation using Time-Sequenced Power Flows

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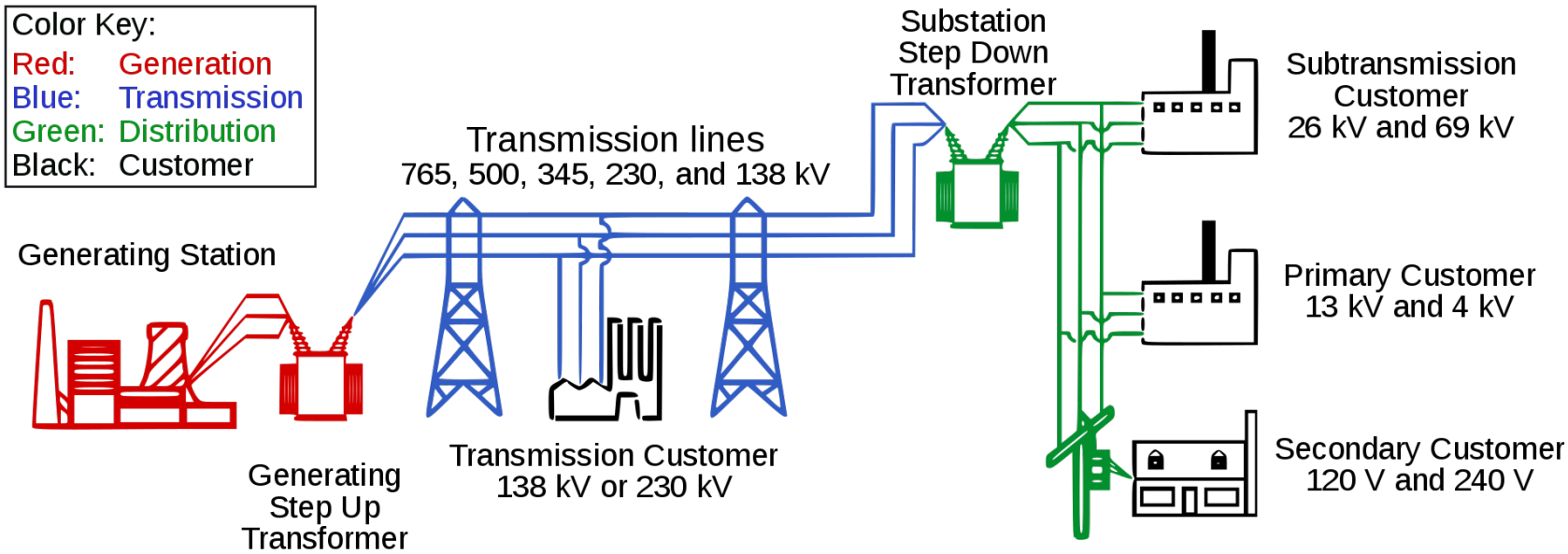
Montana Technological University - Master's Thesis Research Project

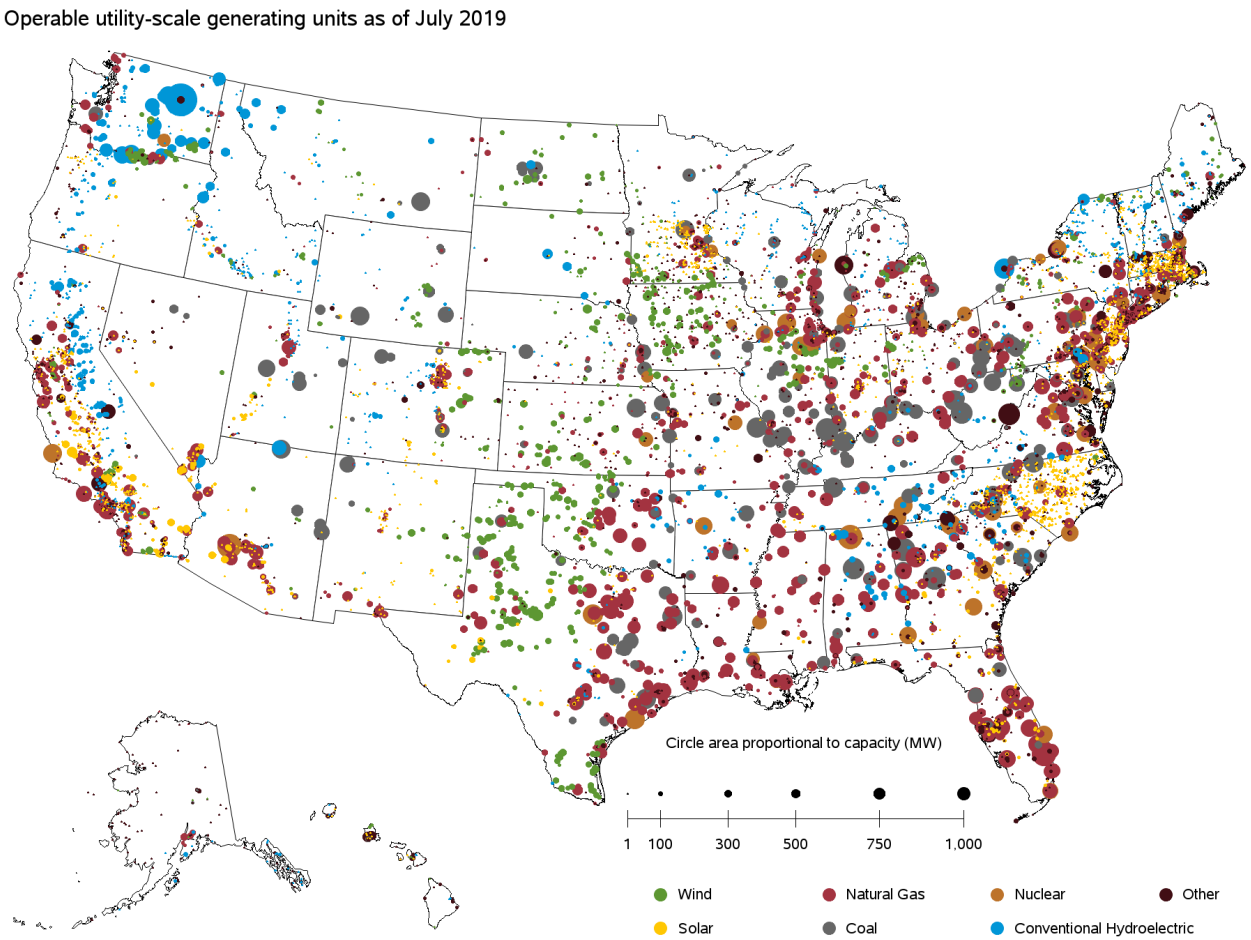
October 22nd, 2019

What is a Power System?

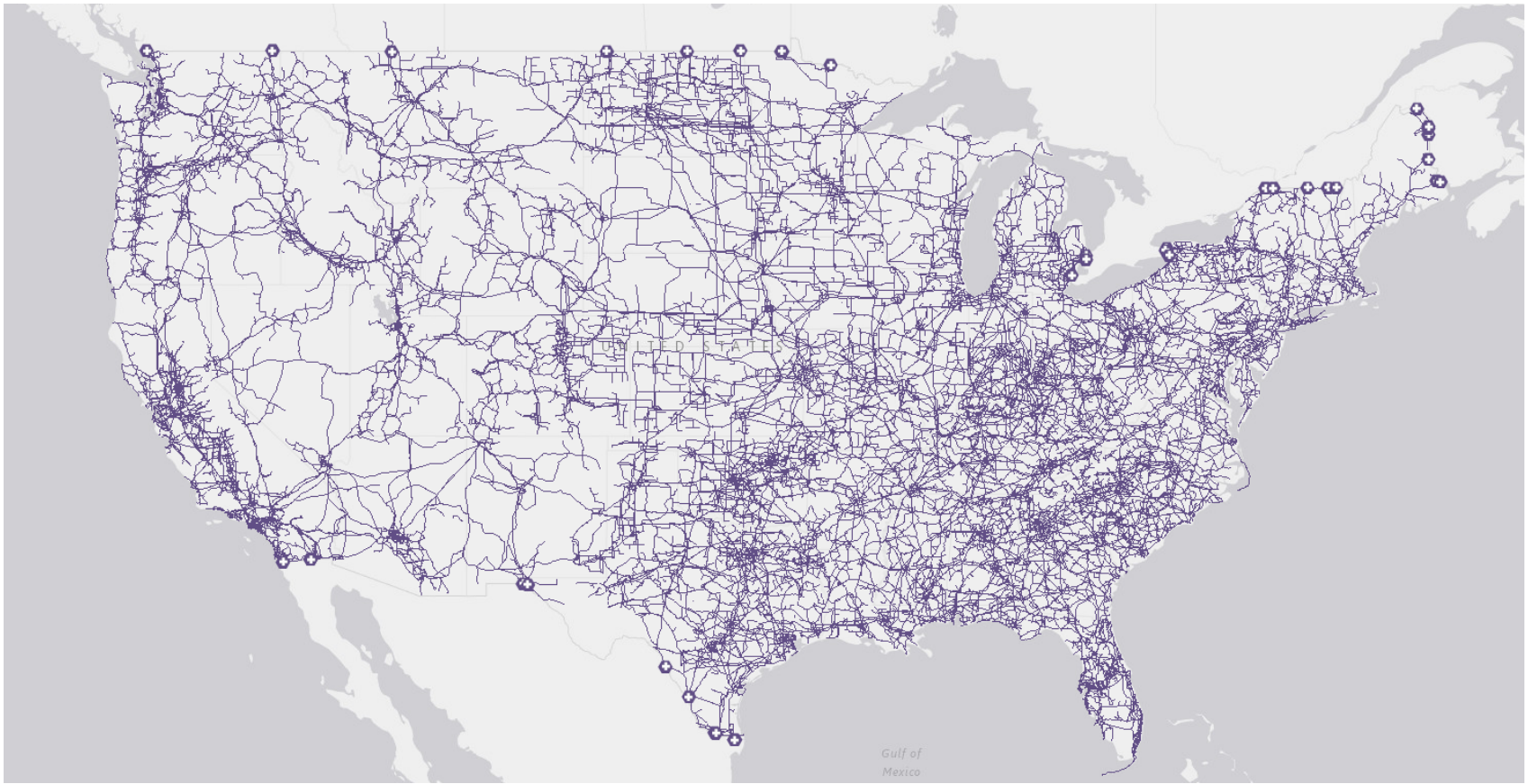


Electrical supply connected to demand.

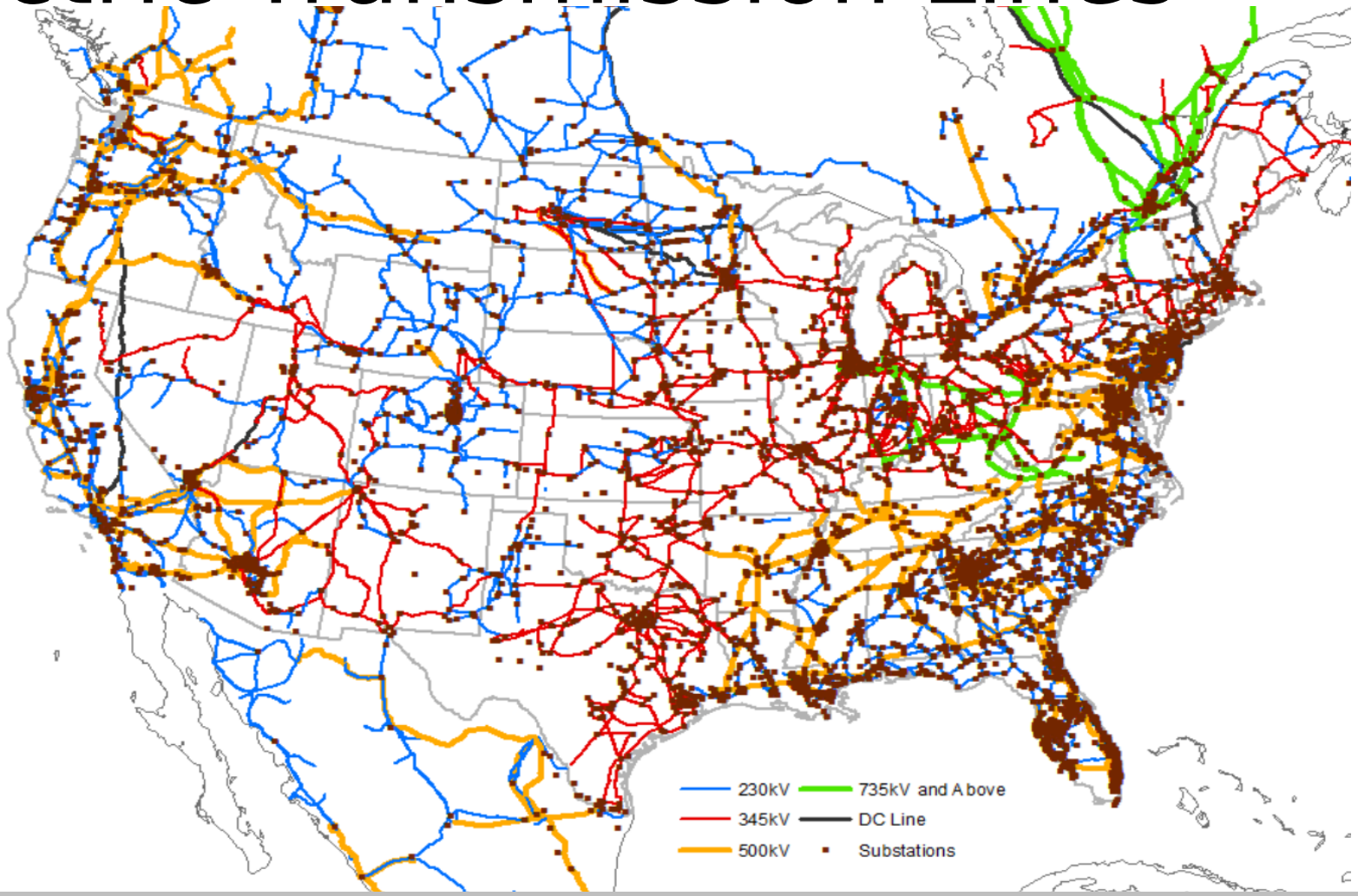
U.S. Electric Generation



U.S. Electric Transmission Lines



Electric Transmission Lines



Interchanges

Interchanges are physical things - it makes sense to bring up here

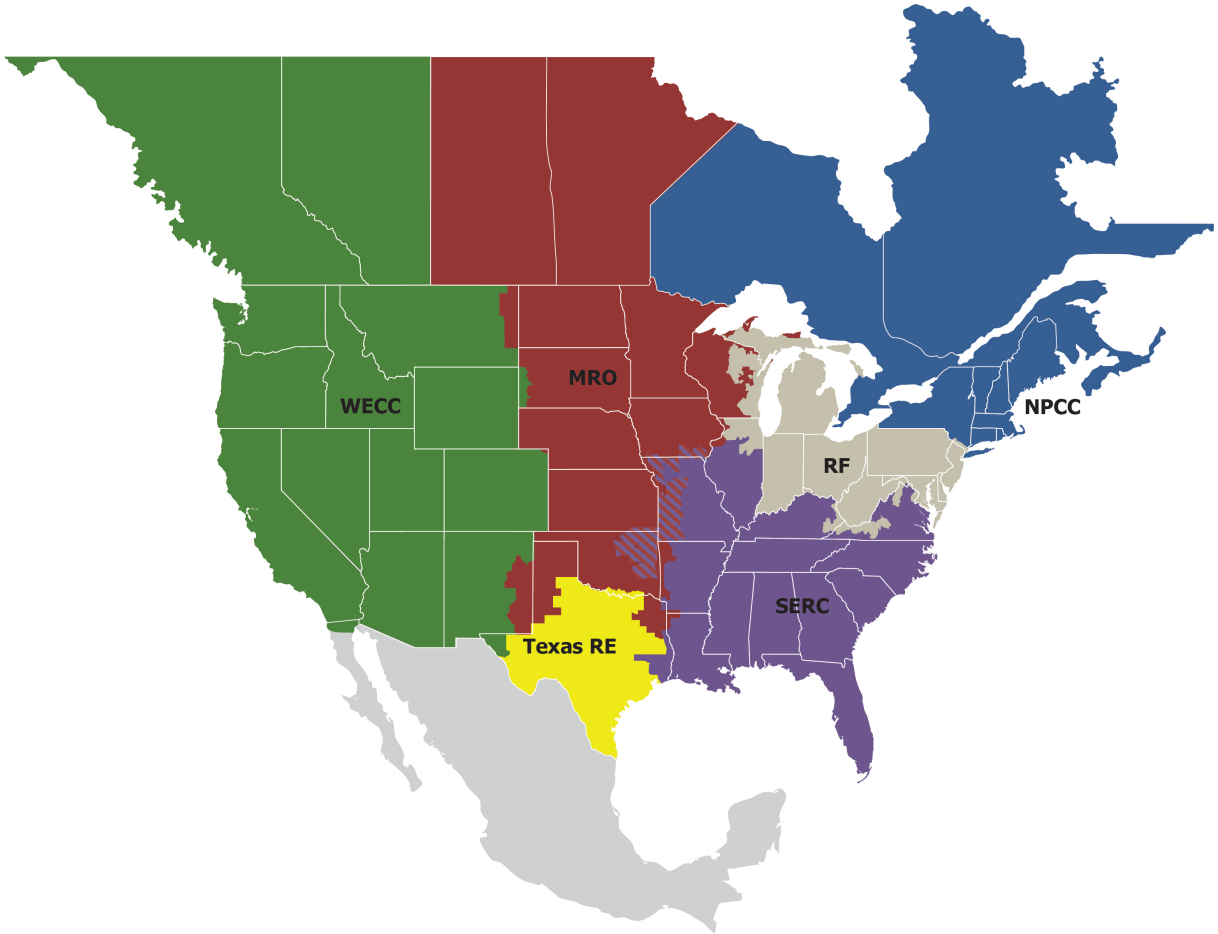
WECC

Current physical location, and it’s what I’m simulating, good idea to bring up here.

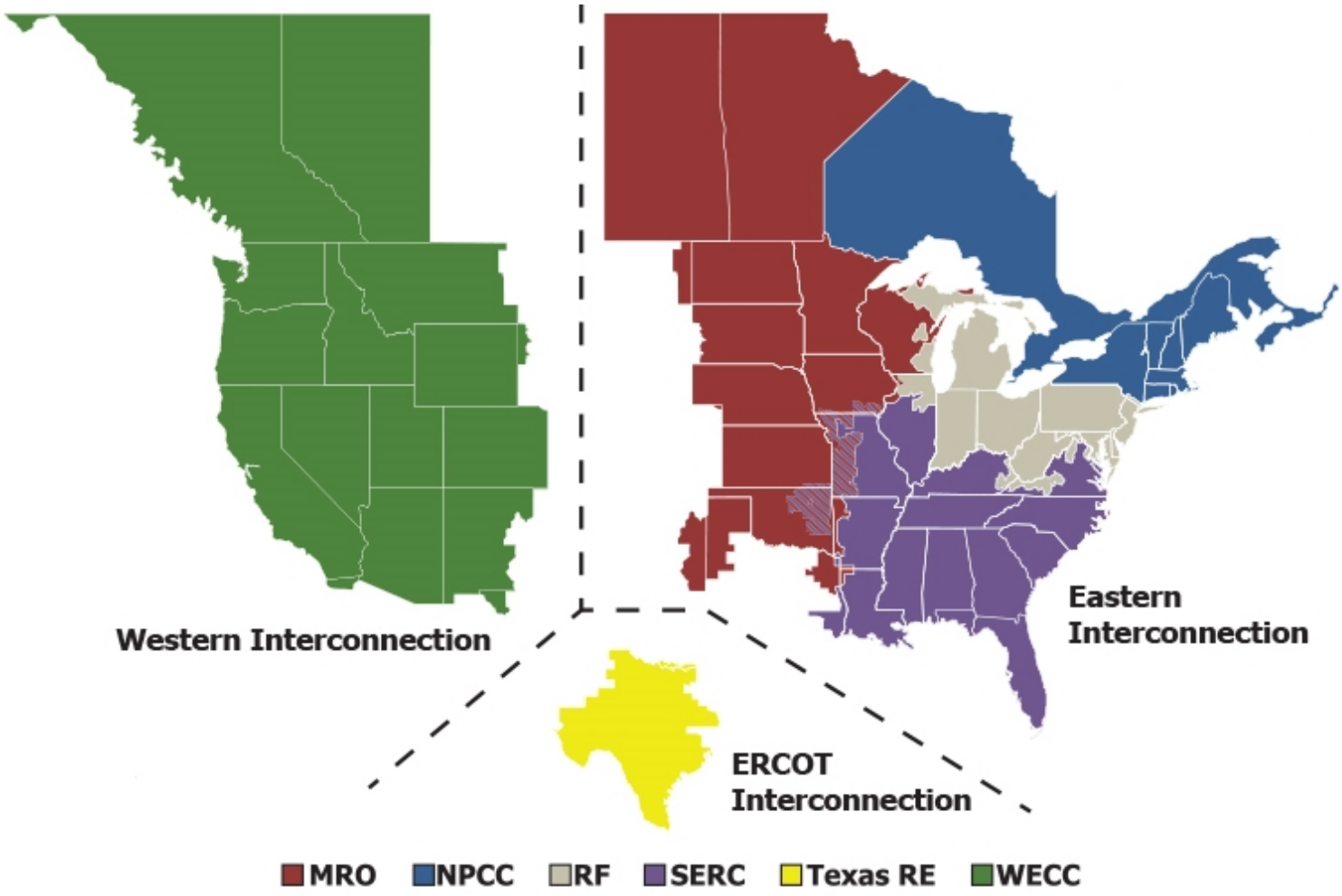
‘People in Charge’

- **FERC** Federal Energy Regulatory Commission
  Part of the Department of Energy
- **NERC** North American Electric Reliability Corp.
  Aurthority granted by FERC
- **Balancing Authorities**
  Manage specific portions of the power system to balance supply and demand and maintain mandatory operating conditions set by FERC and NERC.

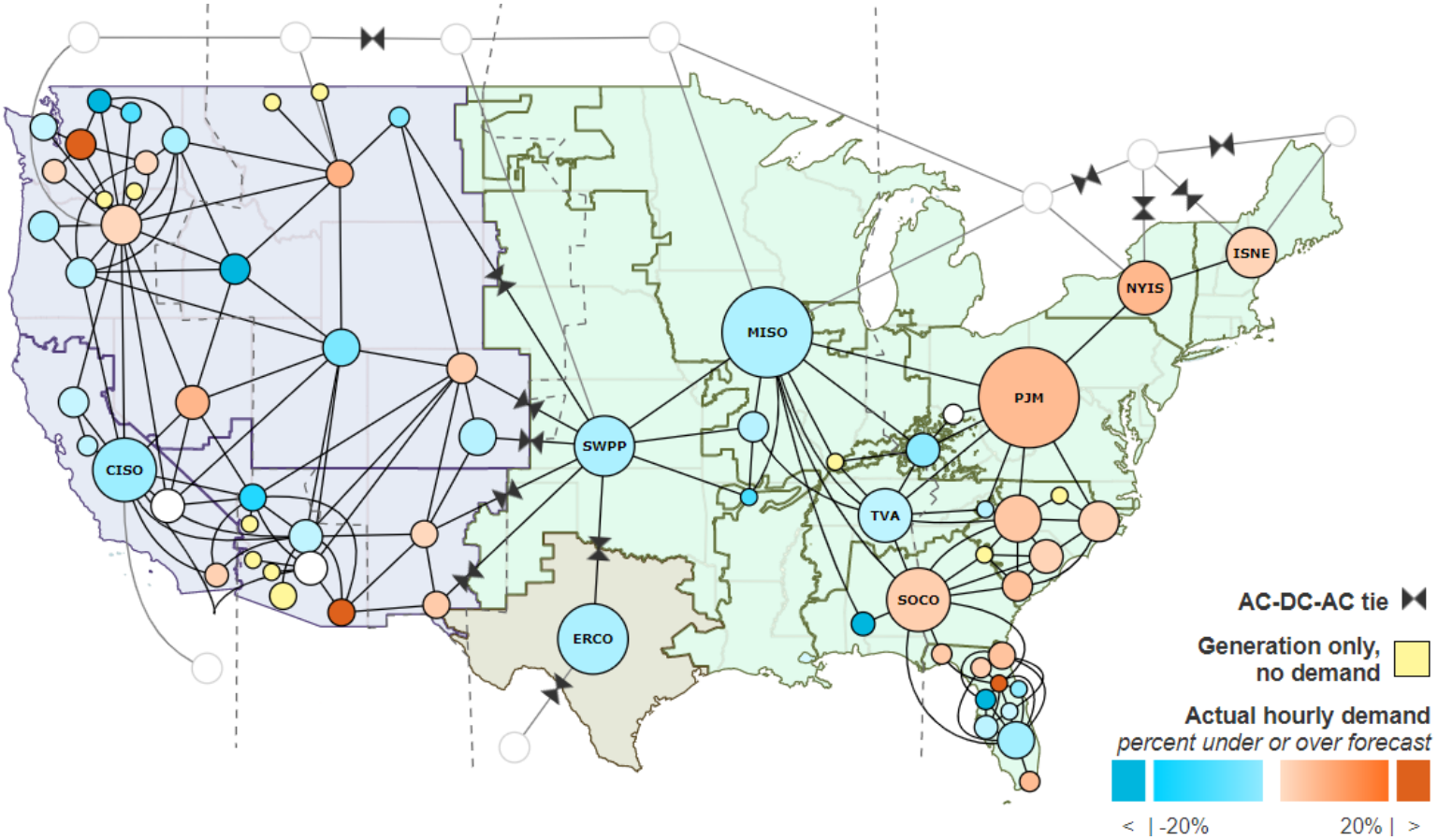
Six NERC Regions



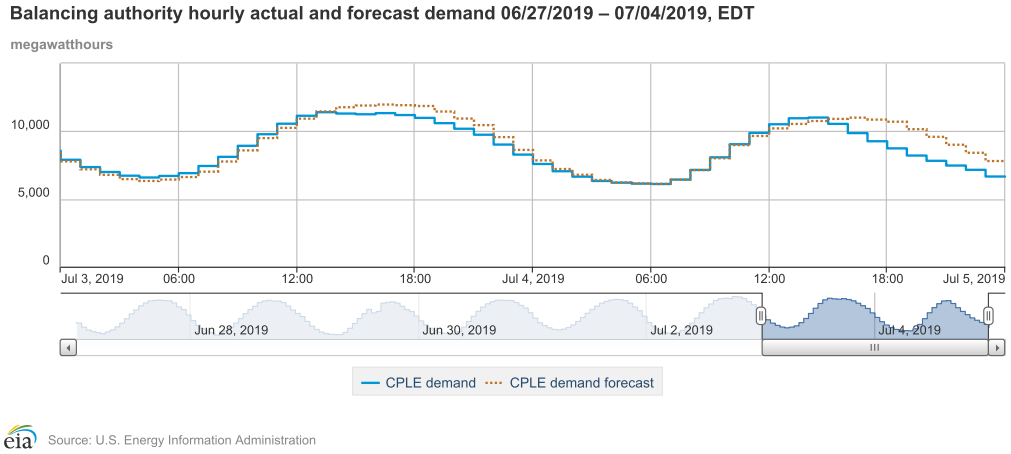
Main Interconnections

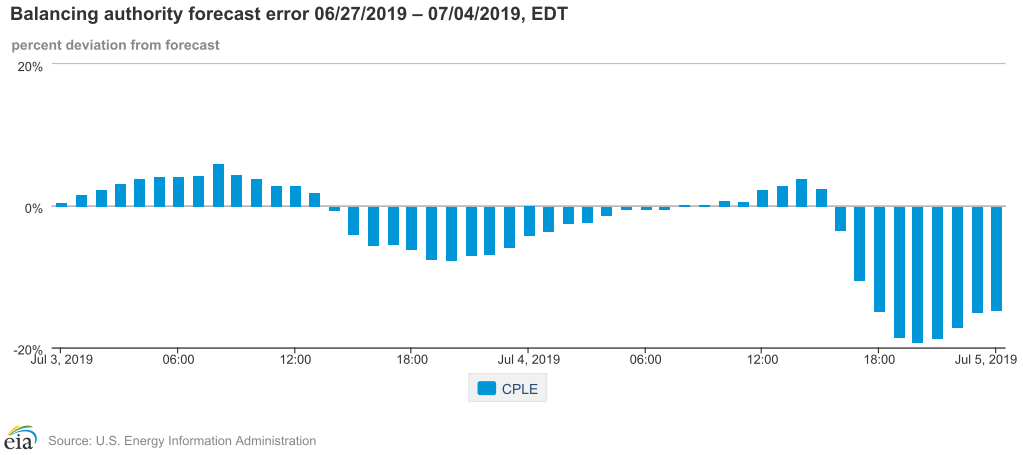


Balancing Authorities (BAs)

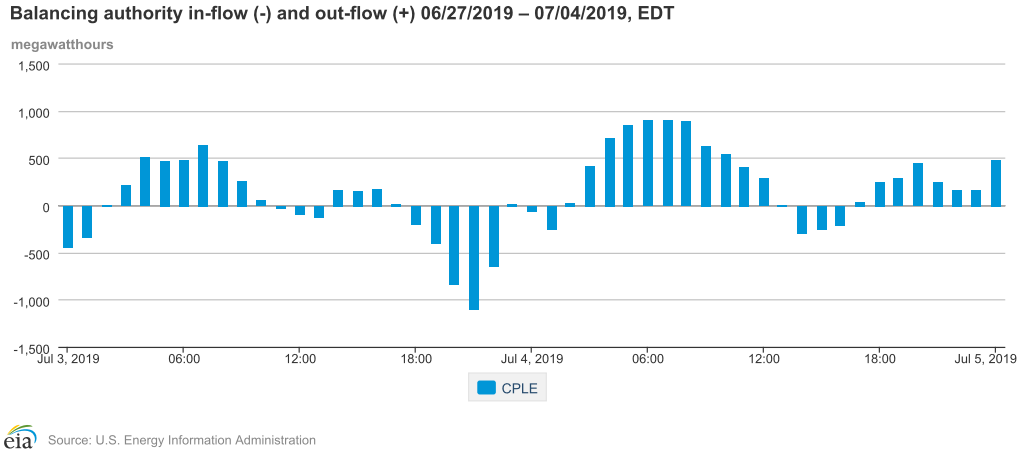


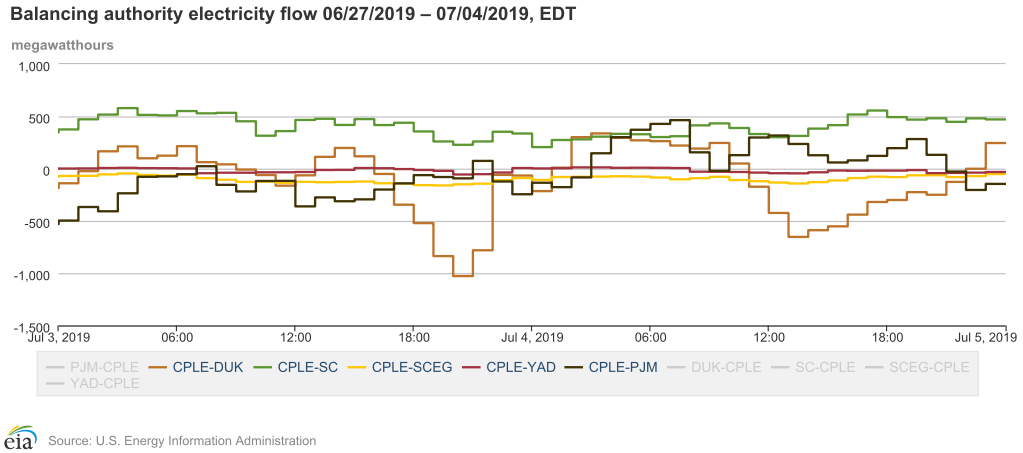
BA Action - Forcasting



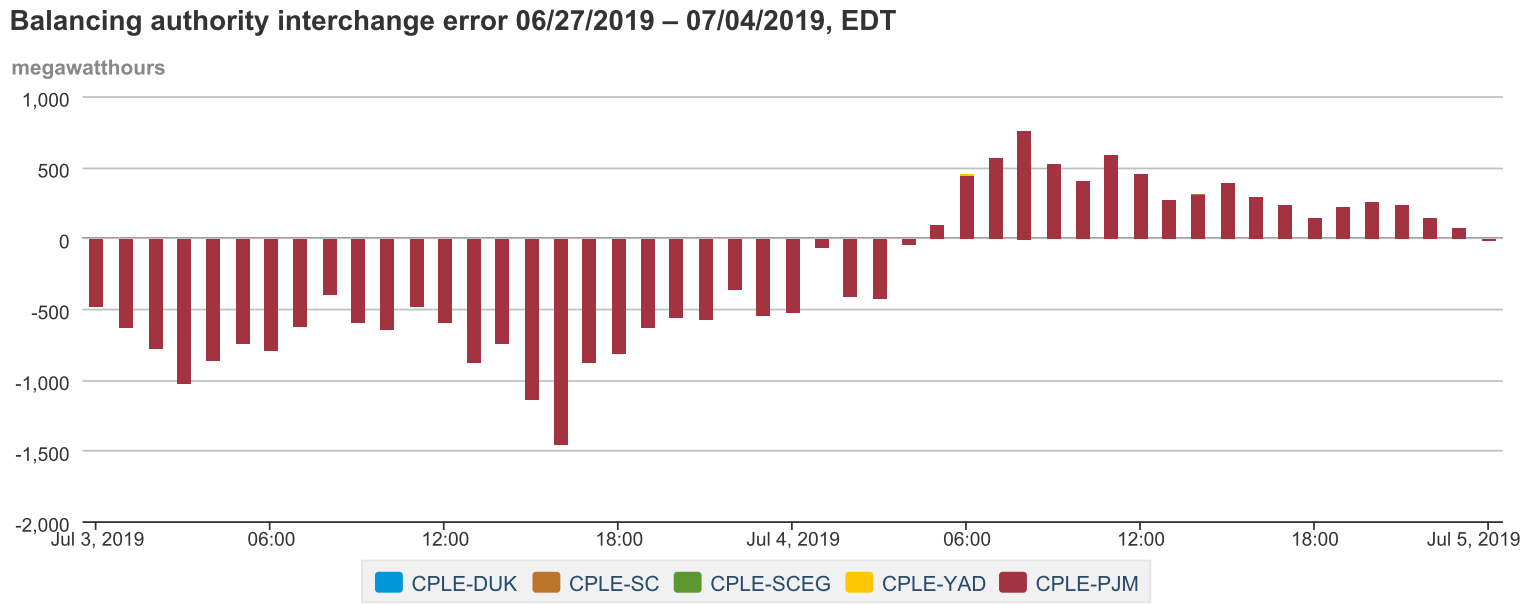


BA Action - Import & Export





BA Action - Interchange Error



eia Source: U.S. Energy Information Administration

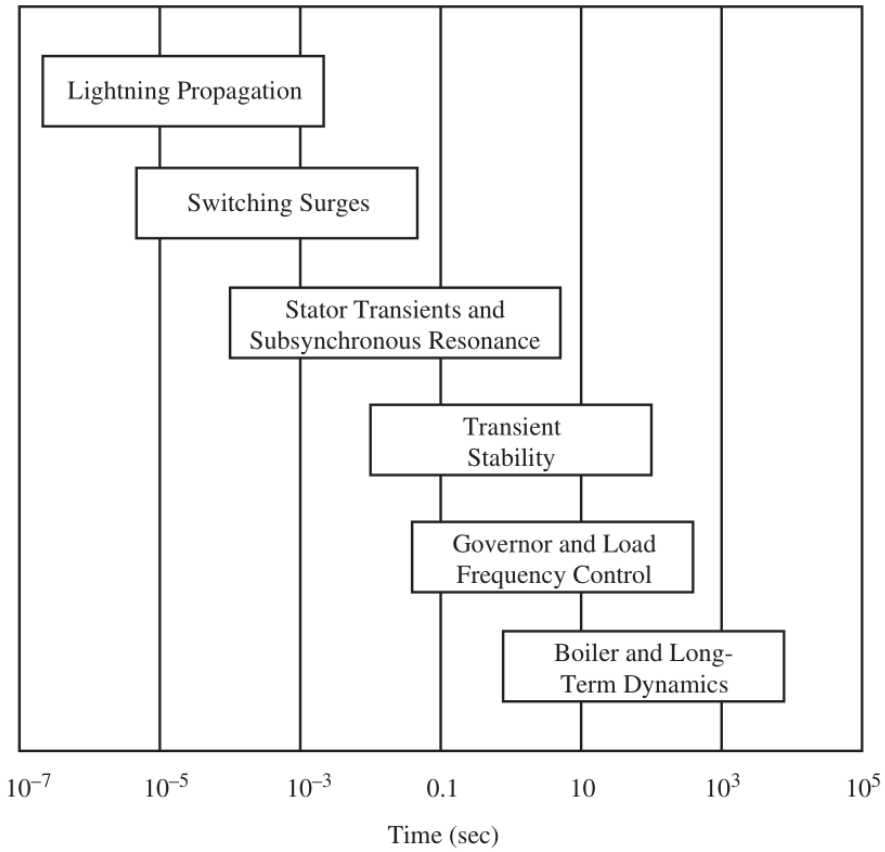
What is Dynamic Simulation?

A computer's mathematical estimation of how a system will change over time.

Think solving ODE's.

How certain qualities of a power system may change over time in response to a known perturbance.

What is Long-Term?



[16]

- 1 sec time step
- 10-60 minute simulations

Generators

Frequency, Accelerating power and Inertia.

$$\dot{\omega}_{sys} = \frac{1}{2H_{sys}} \left(\frac{P_{acc,sys}}{\omega_{sys}(t)} - D_{sys} \Delta\omega_{sys}(t) \right)$$

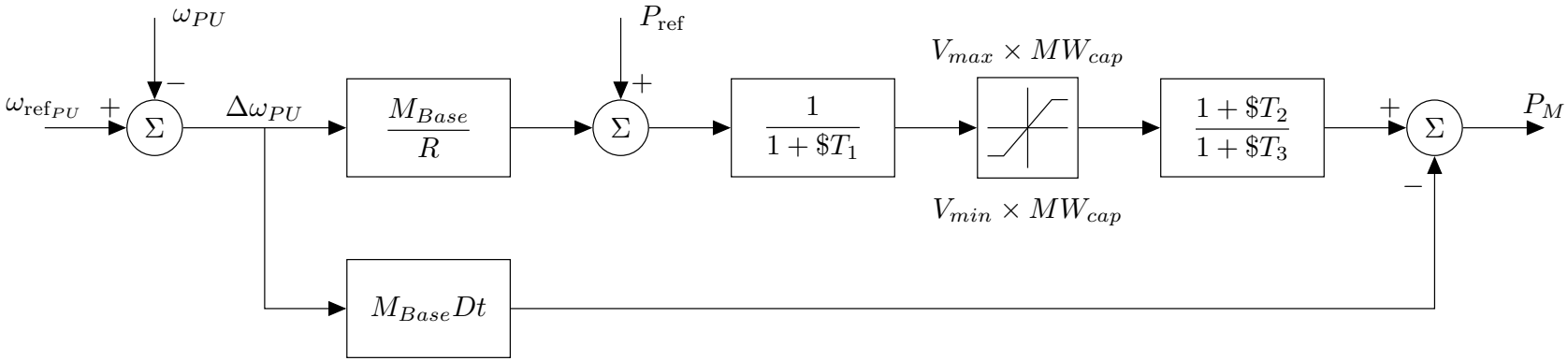
Direct link - electric demand always met. If there isn't enough generation, the kinetic energy stored as a moving inertia in a generator is converted to electric energy and the generator slows down.

Control Reaction Times

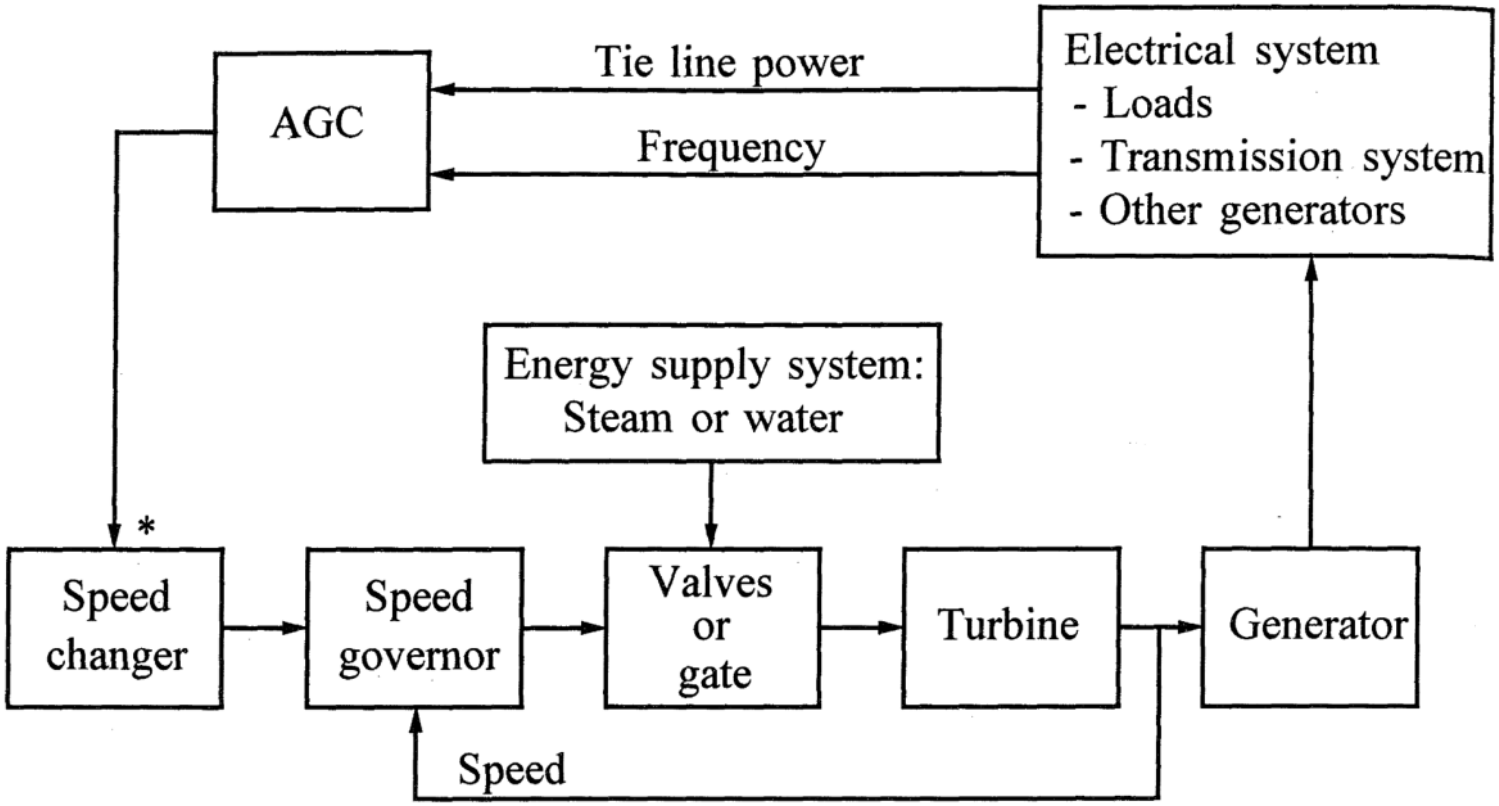
primary, secondary, tertiary
picture...

Turbine Speed Governors

(Governors) Turbine speed governors adjust a machines mechanical power to stop frequency decline. Input is frequency deviation and current operating set point. Classified Primary control.



Automatic Generation Control



* AGC applied only to selected units

[13]

Automatic Generation Control

Adjusts generator nominal operating set point to remove any inadvertent interchange and restore system frequency to 60 Hz. Classified Secondary Control. ACE Conventions Positive ACE denotes over generation. B (the frequency bias) is negative.

$$\text{ACE}_{\text{tie line}} = P_{\text{interchange}} - P_{\text{sched interchange}}$$

$$\text{ACE}_{\text{frequency bias}} = 10B(f_{\text{actual}} - f_{\text{sched}})f_{base}$$

$$\text{ACE} = \text{ACE}_{\text{tie line}} - \text{ACE}_{\text{frequency bias}}$$

Multi-Area Interactions

Areas import or export power to each other.

What is a Power Flow?

A steady state solution to all bus voltages, bus voltage angles, and real and reactive power of a system.

A *snapshot* of a power system.

Power flows are do not care about time.

Time-Sequenced Power Flows?

Multiple power flows arranged in a way to give the allusion of time.

A *flip book* of *snapshots*.

Allows for additional dynamics to be calculated between *snaps*.
(i.e frequency, valve position, . . .)

Transient vs Long-Term Simulation

Time scale. Level of detail required. Equations - transient simulation uses many ODEs to find next steady state and uses very small timesteps, PSLTDSim uses ODE to find next guess of certain inputs to the power flow which then computes the next steady state - uses much large time steps.

So, what's happening?

Essentially:

- Executing computer simulations of the western interconnection that are over 10 minutes long.
- Simulation 'time steps' are a sequence of power flows (*snapshots*)
- Additional dynamic calculations are performed between each 'time step'.

And why?

To study engineering problems involving:

- Long-term events (i.e. Wind Ramps)
- Multi-Area Power Interactions
  - Inadvertent Interchange
  - Turbine governor settings
  - Automatic Generation Control Settings
  - Governor and AGC interaction
- Ways to reduce machine effort while meeting reliability standards.

Quick Initial Validation

pictures of step event comparisons of ltd vs psds

Quick Controller Test

BA controller action - do a with and without thing?

Current Conclusions

- Software (PSLTDSim) output appears valid for small to medium size systems.
- Governor and AGC interactions can happen easily.
- Advanced control can be used to limit governor and AGC conflicts as well as reduce overall machine effort.

Continuing Work

- Experiments with AGC and turbine speed governor settings.
- Use of valve travel and system reliability to gauge validity of control regime.
- Expansion of software capabilities to handle full WECC.

Questions?

References I

[1] P. M. Anderson and A. A. Fouad, *Power System Control and Stability*, Second Edition. Wiley-Interscience, 2003.

[2] A. Aziz, A. Mto, and A. Stojsevski, “Automatic generation control of multigeneration power system,” Journal of Power and Energy Engineering, 2014.

[3] J. Carpentier, “’To be or not to be modern’ that is the question for automatic generation control (point of view of a utility engineer),” International Journal of Electrical Power & Energy Systems, 1985.

[4] F. P. deMello and R. Mills, “Automatic generation control part II - digital control techniques,” IEEE PES Summer Meeting, 1972.

[5] D. Fabozzi and T. Van Cutsem, “Simplified time-domain simulation of detailed long-term dynamic models,” IEEE Xplore, 2009.

[6] GE Energy, *Mechanics of running pslf dynamics*, 2015.

References II

[7] General Electric International, Inc, *PSLF User's Manual*, 2016.

[8] W. B. Gish, "Automatic generation control algorithm - general concepts and application to the watertown energy control center," Bureau of Reclamation Engineering and Research Center, 1980.

[9] J. D. Glover, M. S. Sarma, and T. J. Overbye, *Power System Analysis & Design*, 5e. Cengage Learning, 2012.

[10] M. Goossens, F. Mittelbach, and A. Samarin, *The LaTeX Companion*. Addison-Wesley, 1993.

[11] E. Heredia, D. Dosterev, and M. Donnelly, "Wind hub reactive resource coordination and voltage control study by sequence power flow," IEEE, 2013.

References III

[12] Y. G. Kim, H. Song, and B. Lee, “Governor-response power flow (grpf) based long-term voltage stability simulation,” IEEE T&D Asia, 2009.

[13] P. Kundur, *Power System Stability and Control*. McGraw-Hill, 1994.

[14] Y. Mobarak, “Effects of the droop speed governor and automatic generation control agc on generator load sharing of power system,” International Journal of Applied Power Engineering, 2015.

[15] B. Rand. (2018), Agent-based modeling: What is agent-based modeling? Youtube, [Online]. Available: https://www.youtube.com/watch?v=FVmQbfsOkGc.

[16] P. W. Sauer, M. A. Pai, and J. H. Chow, *Power System Dynamics and Stability With Synchrophasor Measurement and Power System Toolbox*, Second Edition. John Wiley & Sons Ltd, 2018.

References IV

[17] M. Stajcar, “Power system simulation using an adaptive modeling framework,” Master’s thesis, Montana Tech, 2016.

[18] C. W. Taylor and R. L. Cresap, “Real-time power system simulation for automatic generation control,” IEEE Transactions on Power Apparatus and Systems, 1976.

[19] T. Van Cutsem and C. Vournas, *Voltage Stability of Electric Power Systems*, 1st ed. Springer US, 1998.