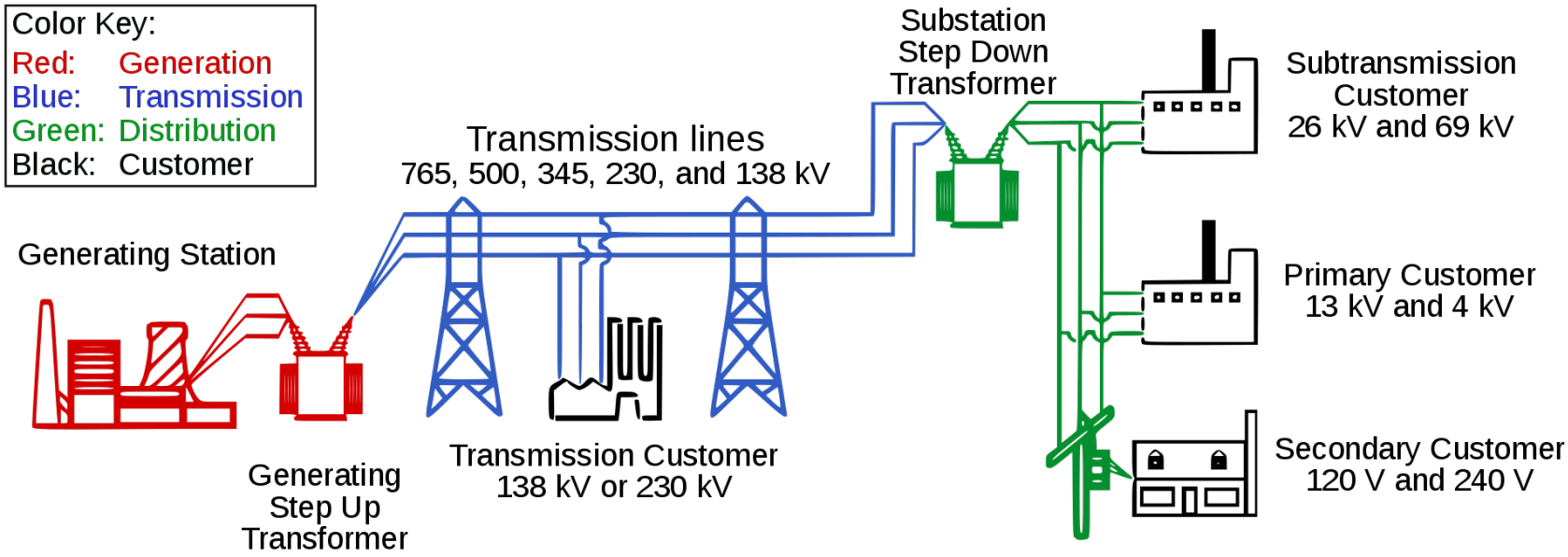
Power System Long-Term Dynamic Simulation using Time-Sequenced Power Flows

Thad Haines

Montana Technological University - Master's Thesis Research Project

October 22nd, 2019

What is a Power System?

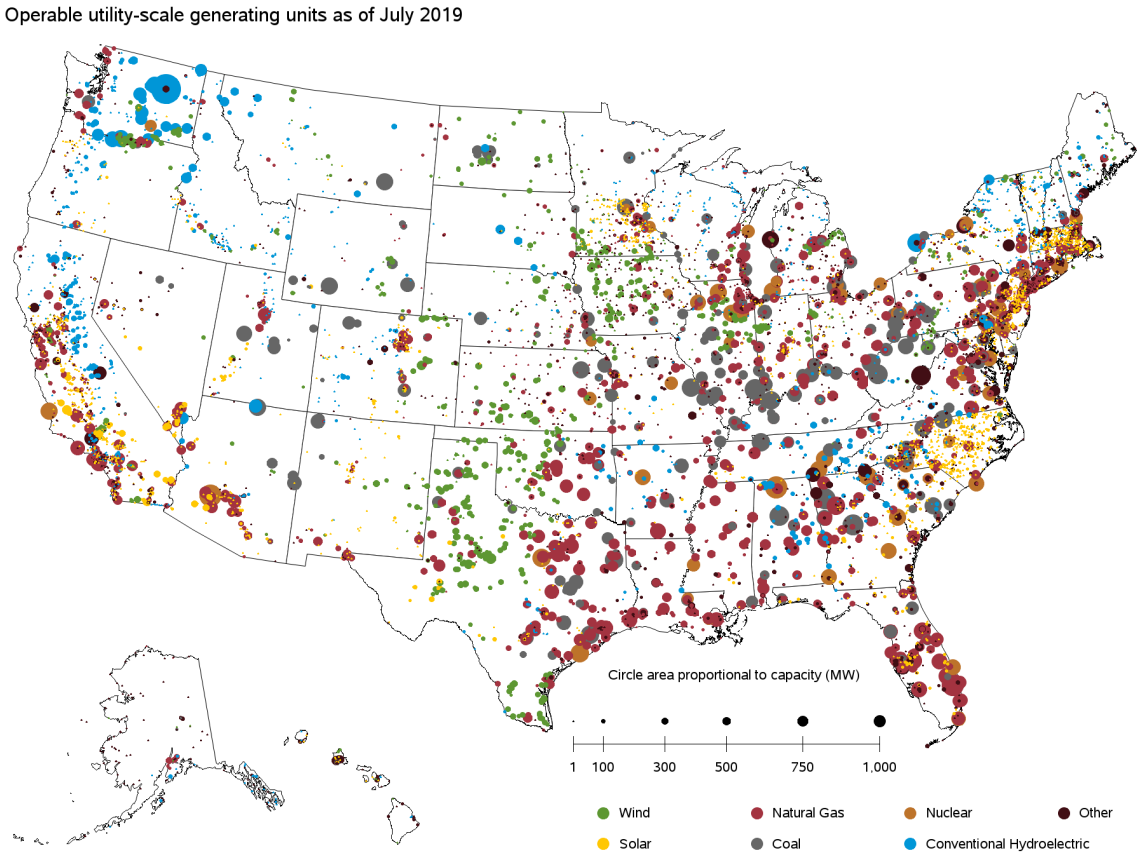


[15]

Electrical supply connected to demand.

Research focus on transmission system.

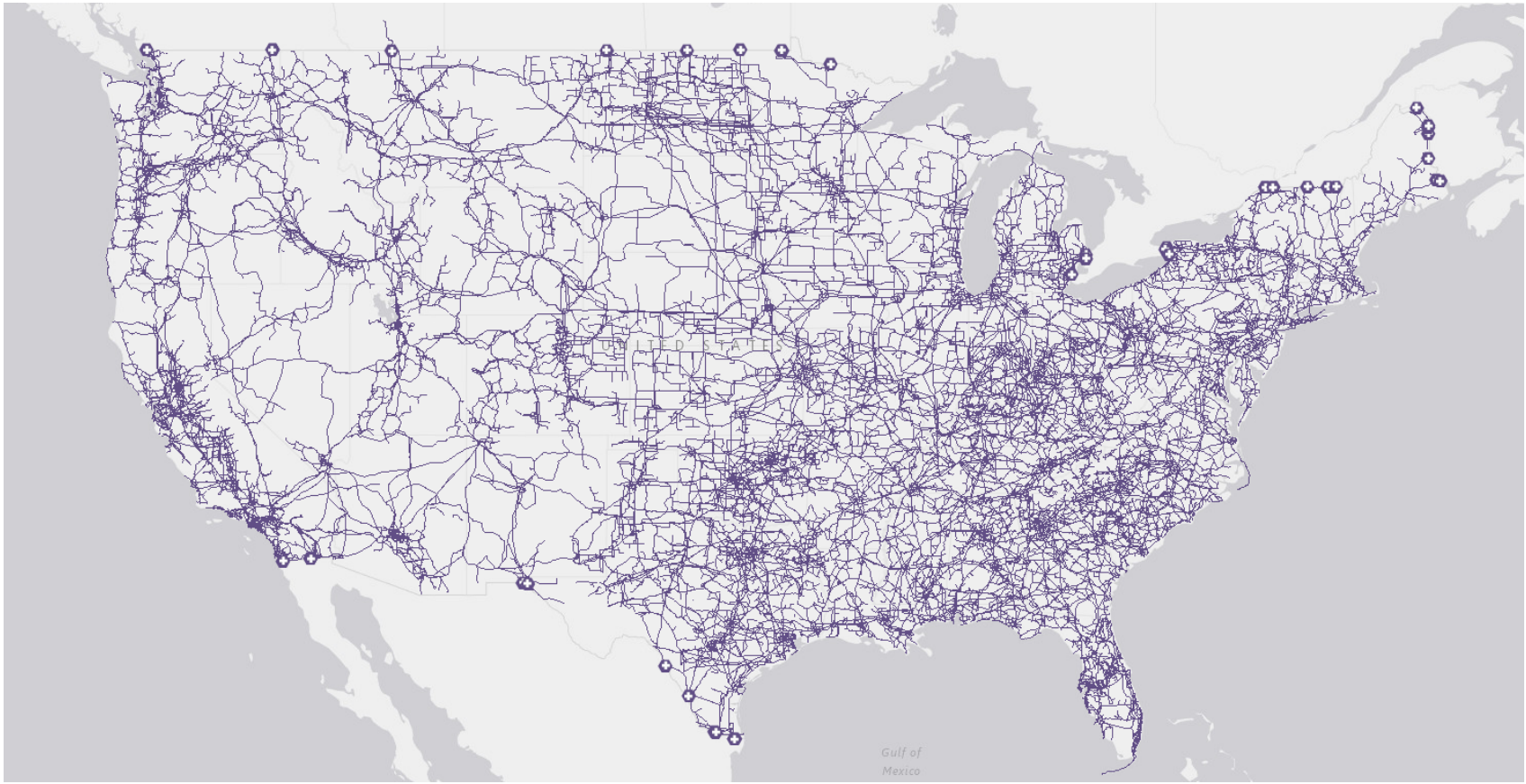
U.S. Electric Generation



Sources: U.S. Energy Information Administration, Form EIA-860, 'Annual Electric Generator Report' and Form EIA-860M, 'Monthly Update to the Annual Electric Generator Report.'

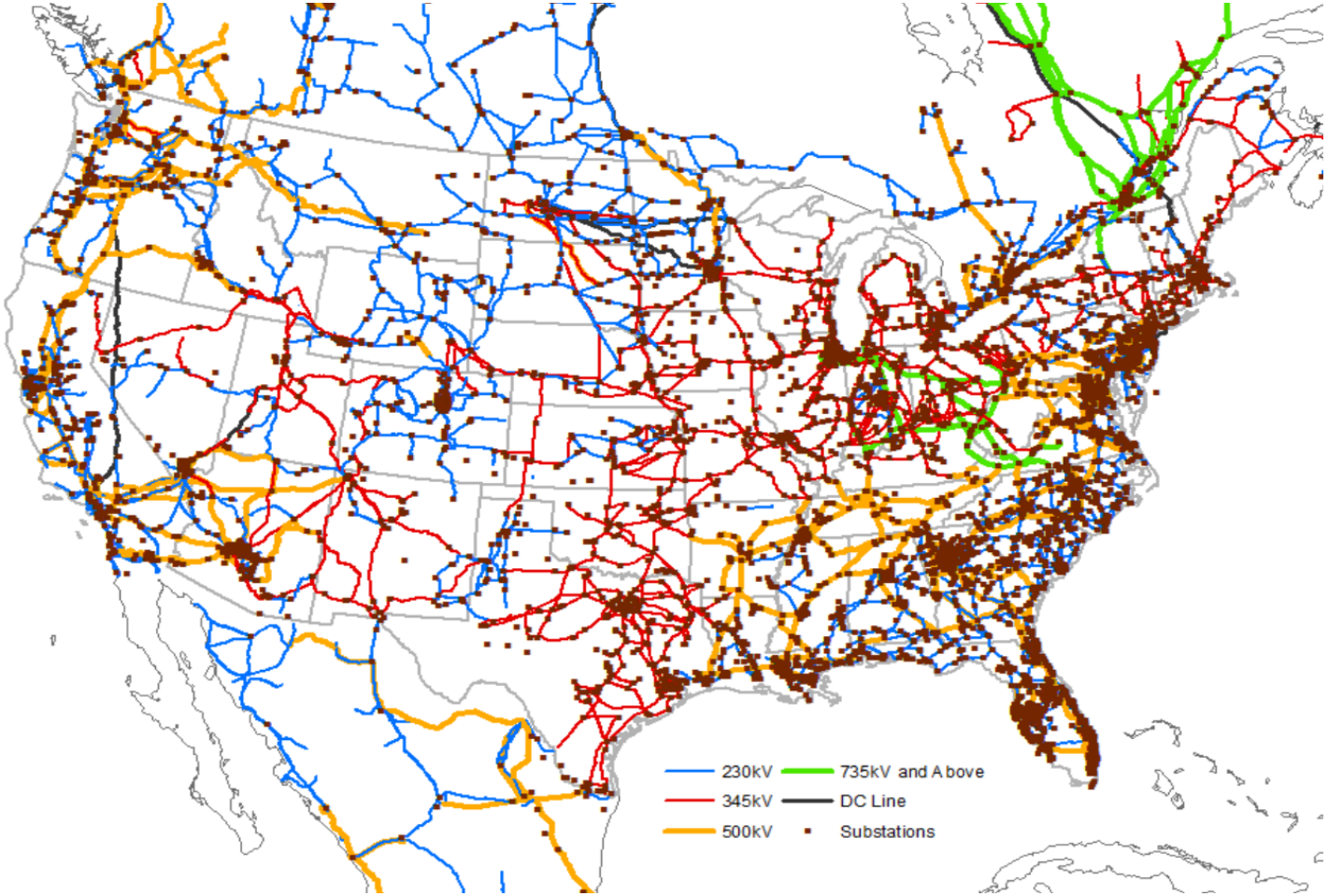
[16]

U.S. Electric Transmission Lines



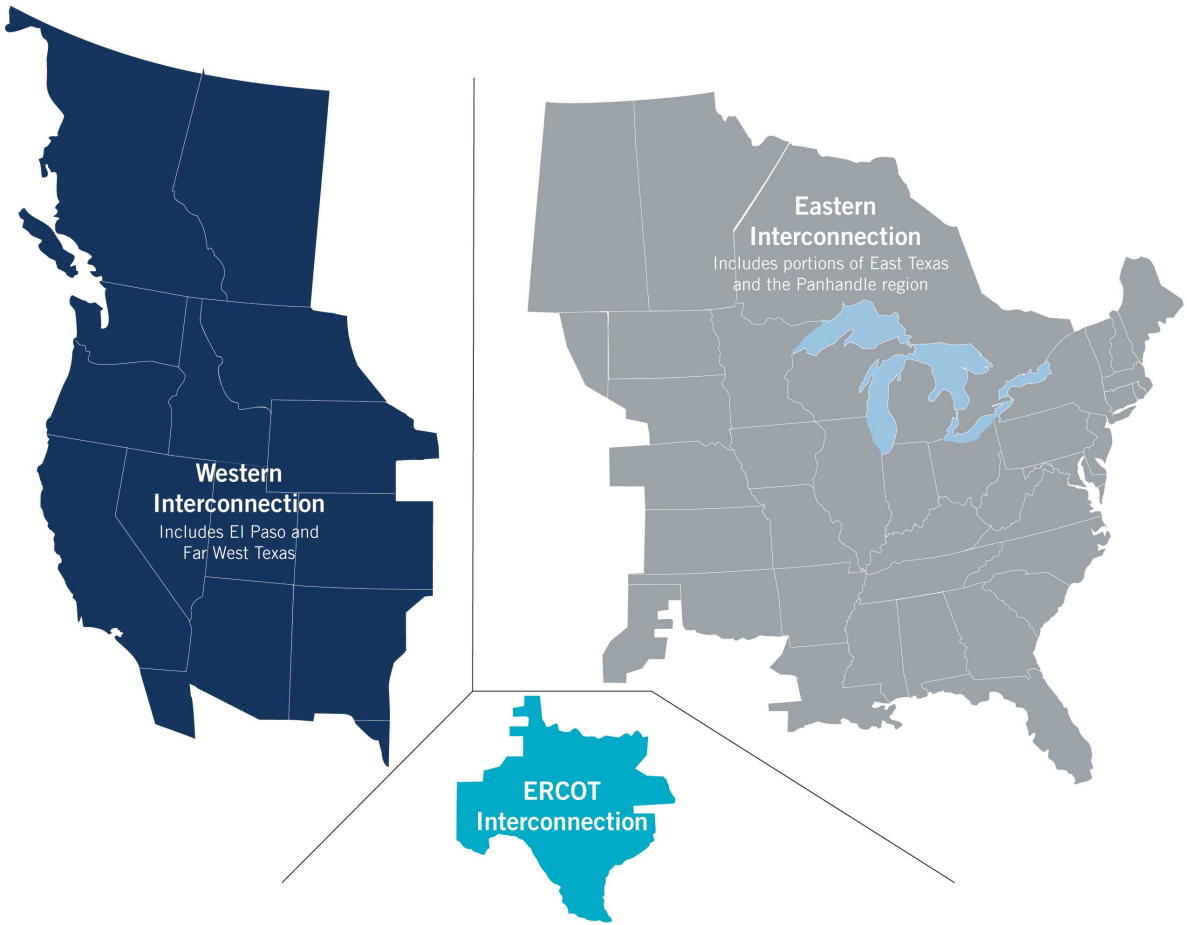
[29]

Electric Transmission Lines



[21]

Interconnections



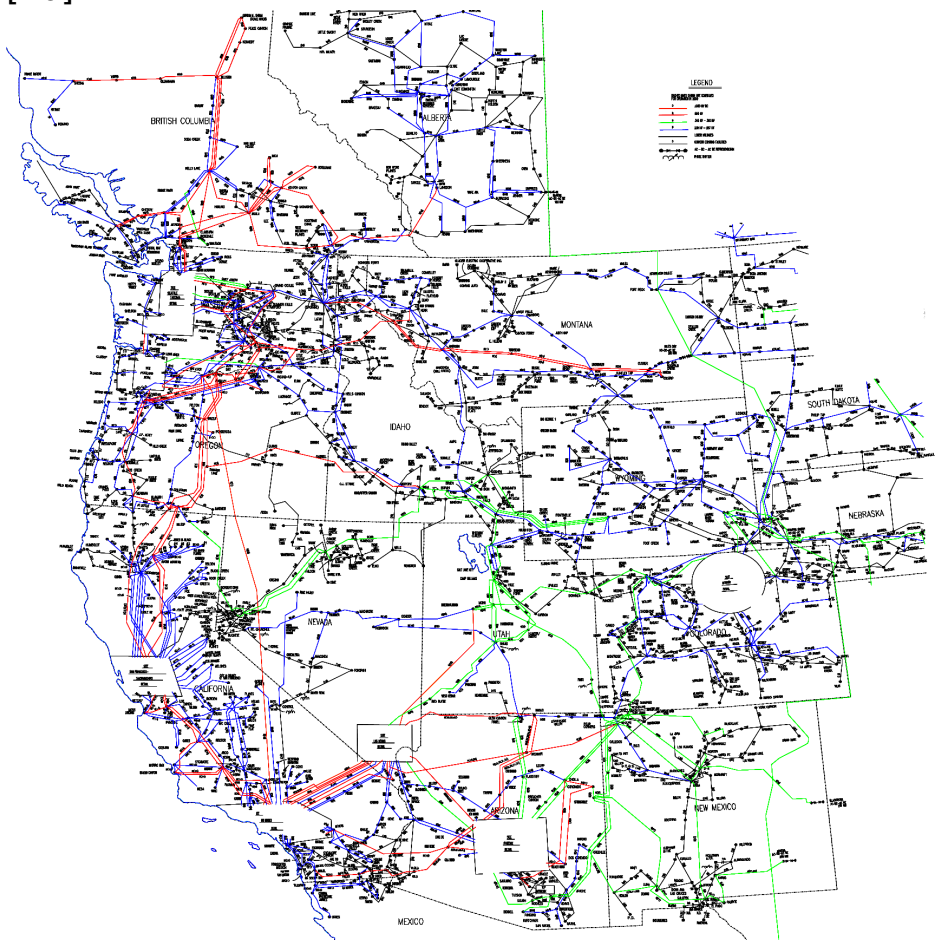
[6]

Industry Software Model

WECC Model (GE PSLF)

- 4,231 Generators
- 17,210 Lines
- 22 Areas
- 11,048 Loads
- 21,879 Buses

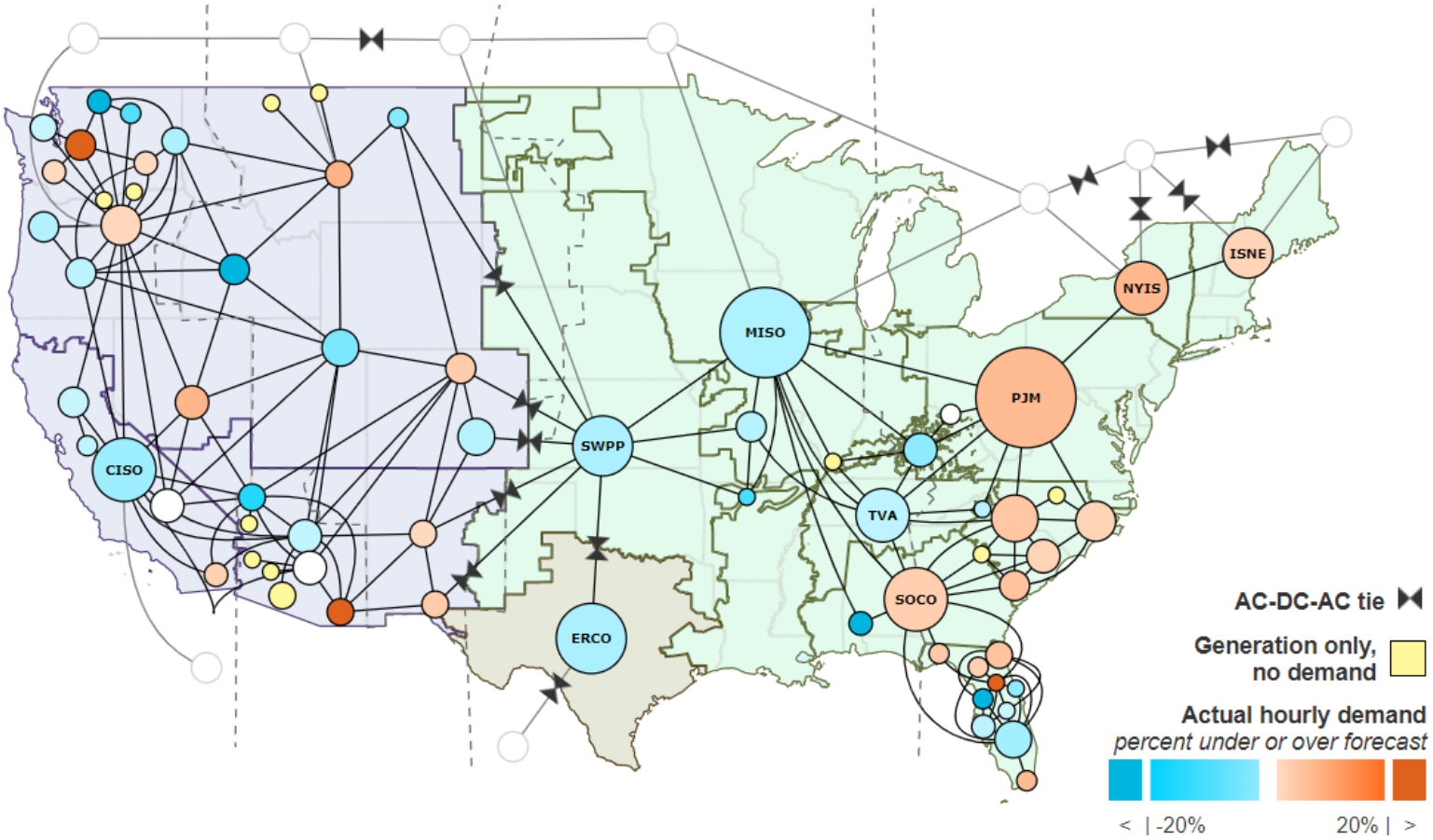
[20]



‘People in Charge’

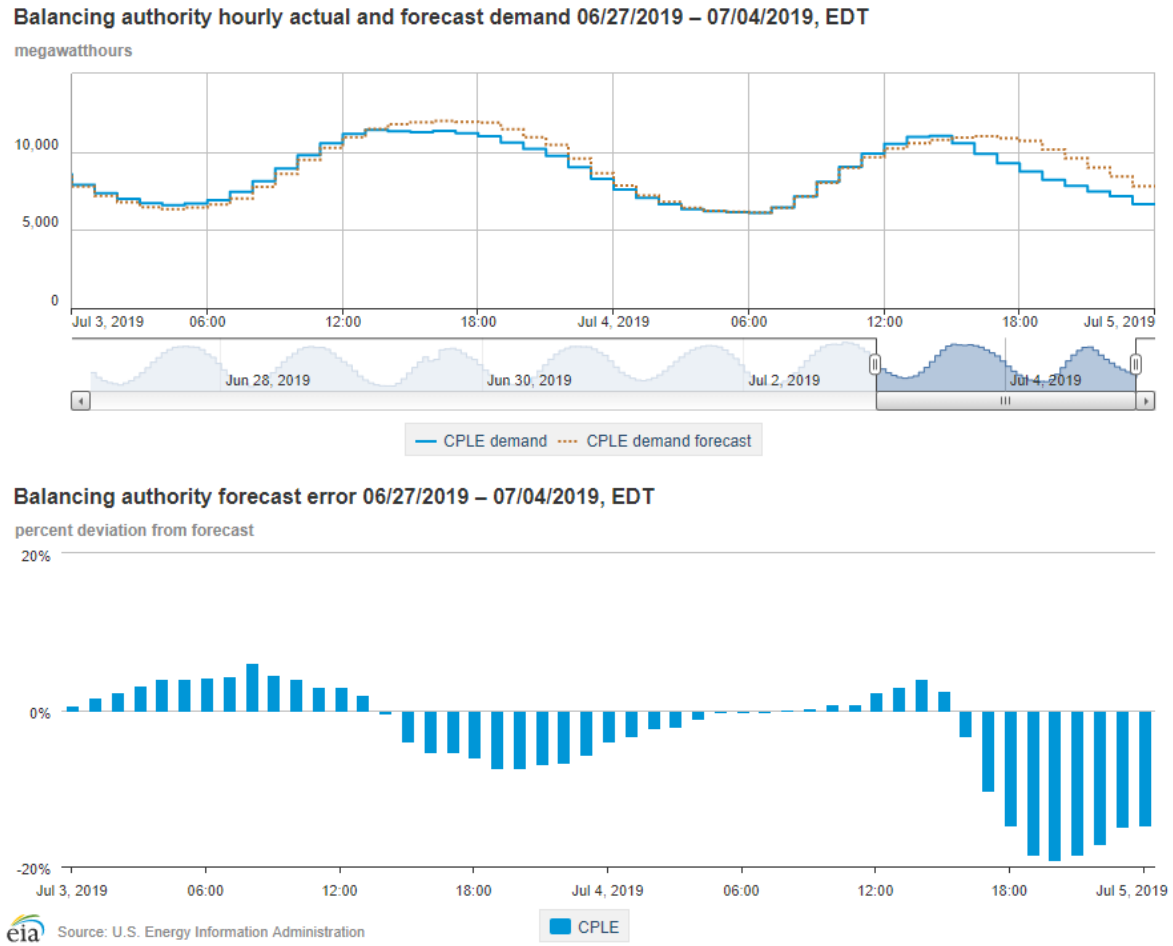
- **FERC** Federal Energy Regulatory Commission
  Part of the Department of Energy
- **NERC** North American Electric Reliability Corp.
  Aurthority granted by FERC
- **Balancing Authority** (BA)
  Manage specific portions of the power system to balance supply and demand and maintain mandatory operating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

Balancing Authorities (BAs)



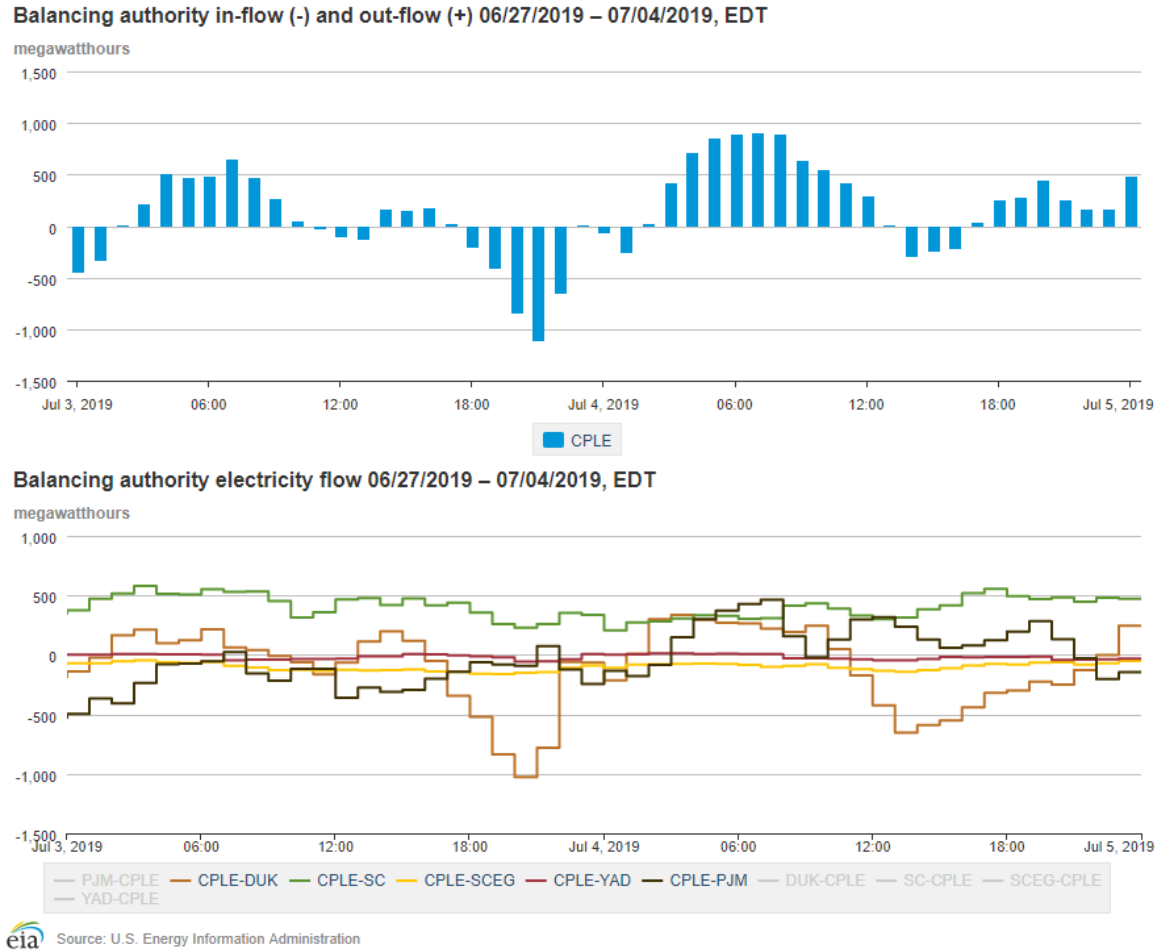
[28]

BA Action - Forcasting



[28]

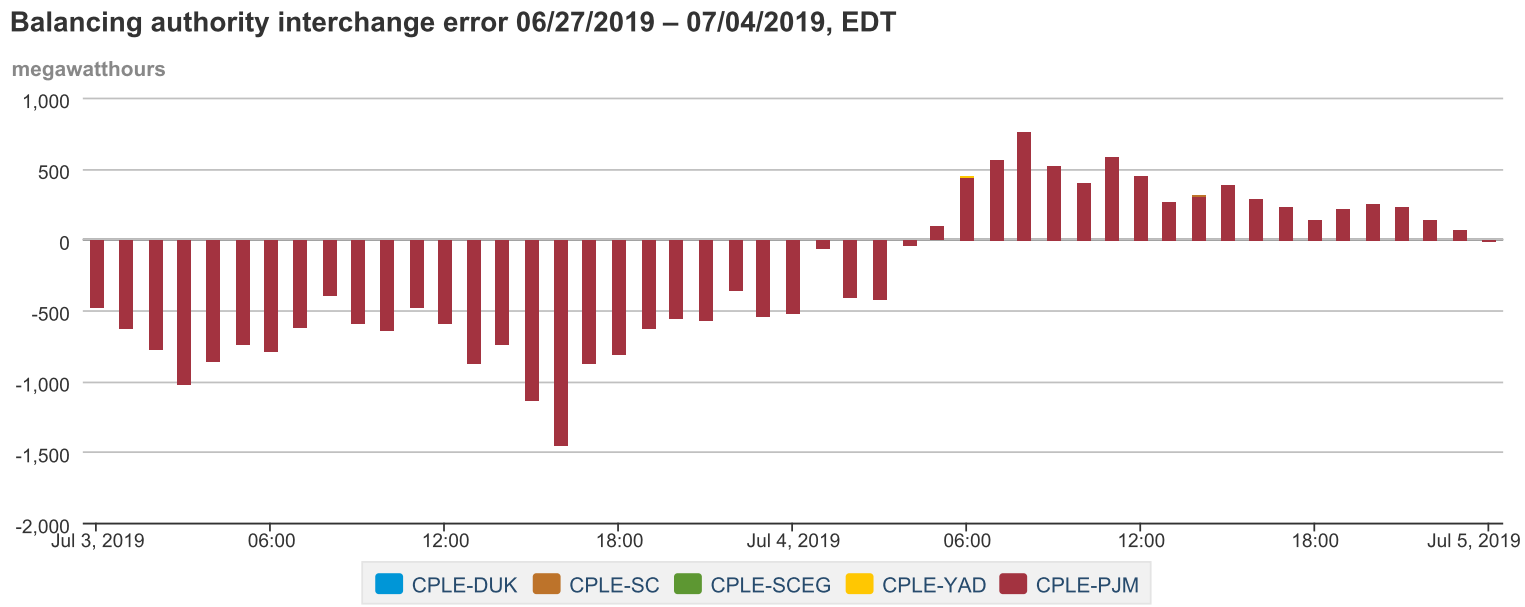
BA Action - Interchange



[28]

BA Action - Interchange Error

≈ Area Control Error



eia Source: U.S. Energy Information Administration

[28]

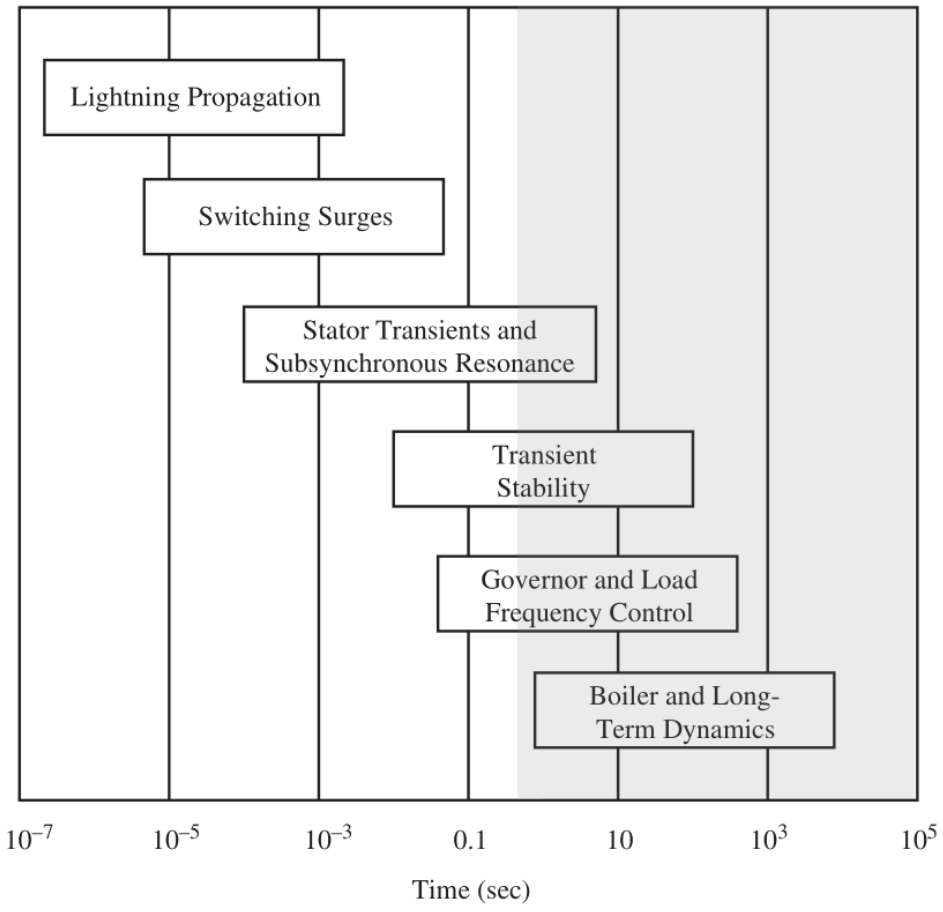
What is Dynamic Simulation?

A computer's mathematical solution to how a system may change over time.

Think solving ODE's.

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

What is Long-Term?



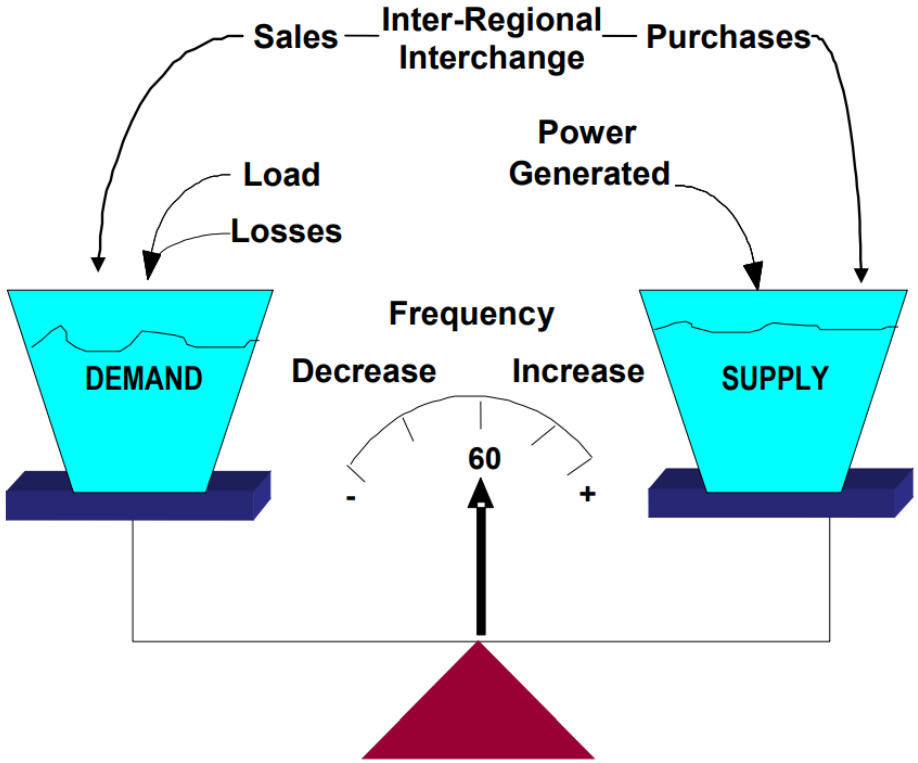
[23]

- 1 sec $\leftrightarrow$ hours
  $\therefore$
- 10$\rightarrow$60 minute simulations
- 1 sec time step

Frequency (ω)

$$\dot{\omega}_{sys} = \frac{P_{acc,sys}}{2H_{sys}\omega_{sys}(t)}$$

$$P_{acc} = P_{gen} - P_{load}$$

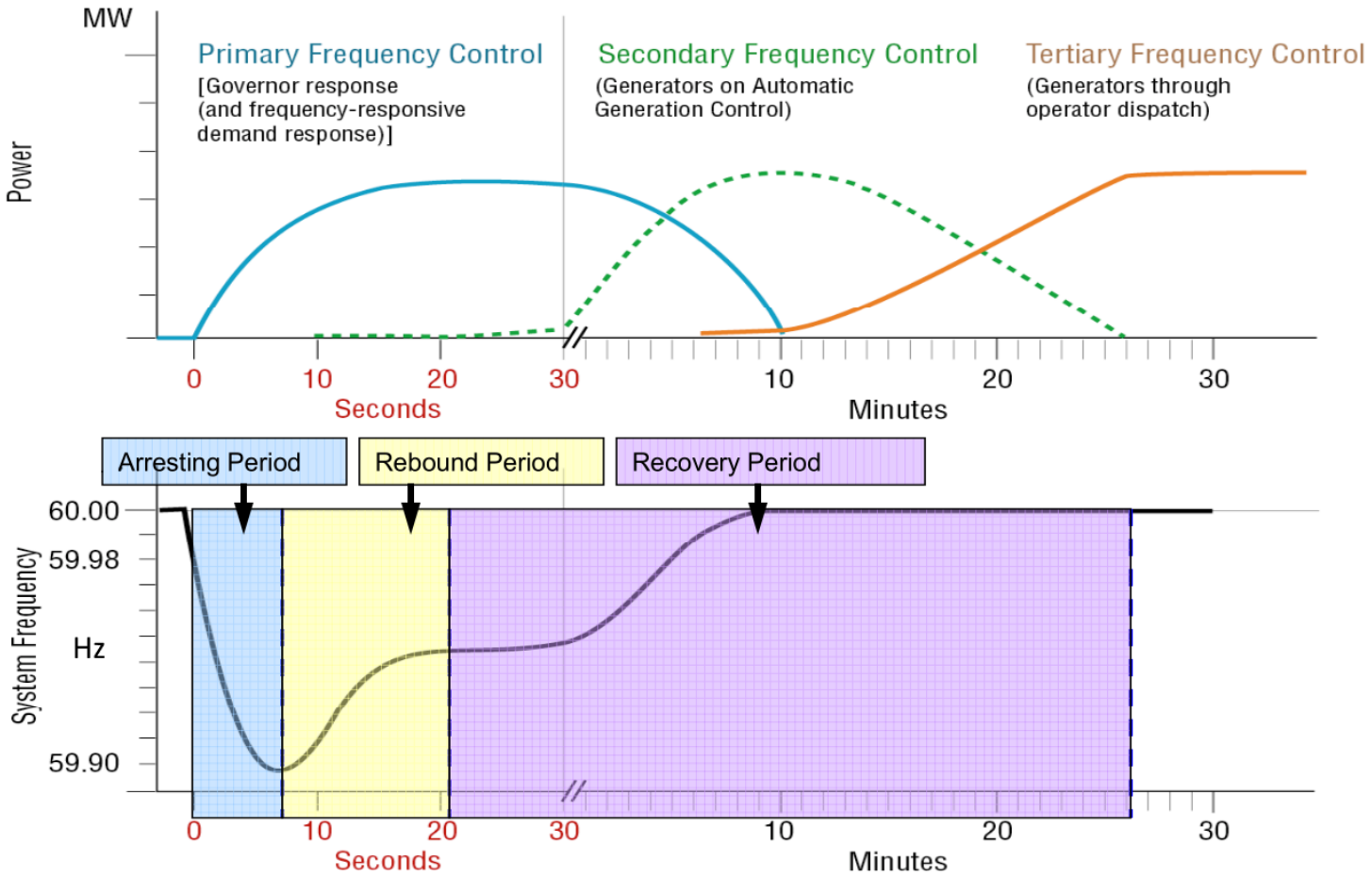


Electric load always met.

Load and losses always changing.

[25]

Automatic Controls



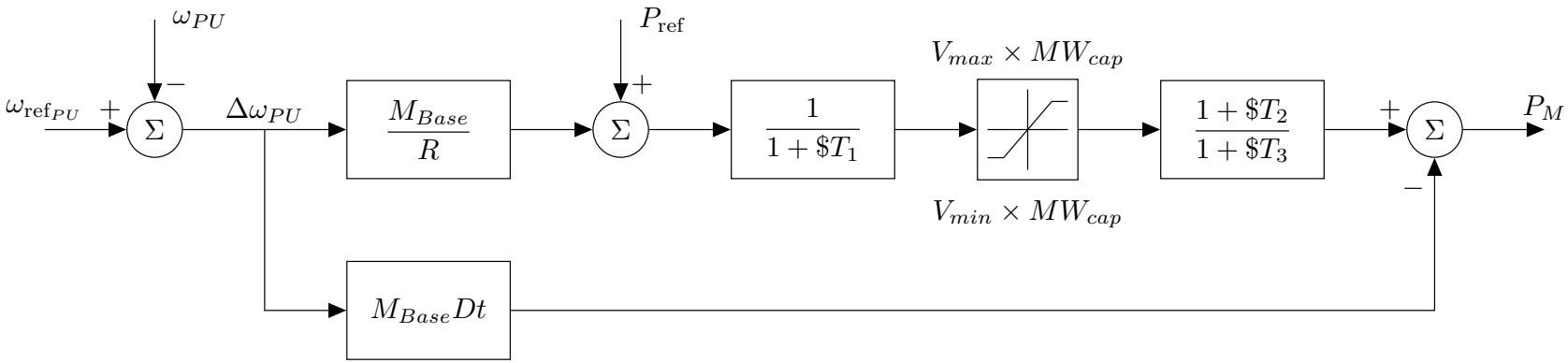
[4]

Turbine Speed Governors

Primary Control

Purpose: Adjust turbine mechanical power to arrest frequency decline.

Dynamic Variable: Fuel Valve Position

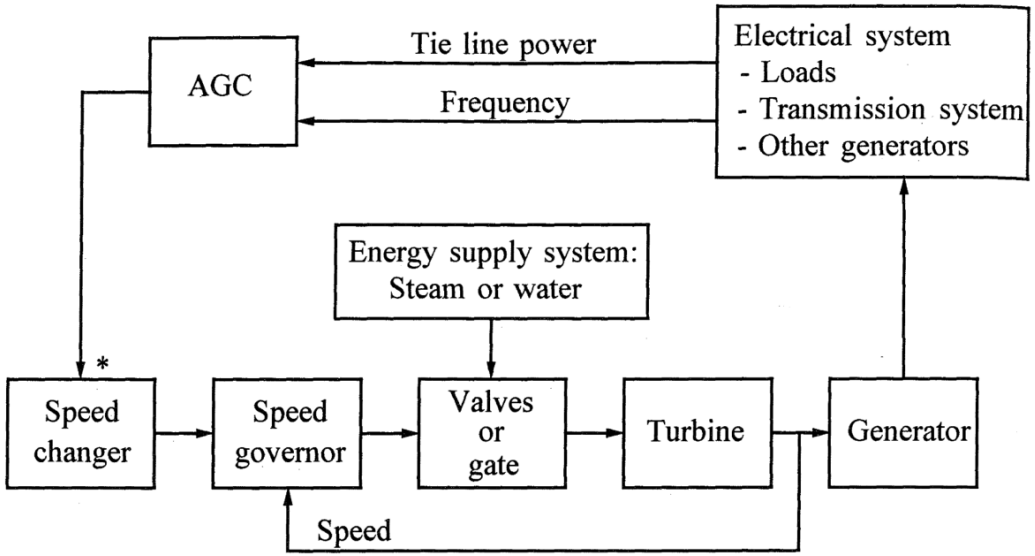


Automatic Generation Control

Secondary Control

Purpose: Eliminate Area Control Error

Dynamic Variable: Area Control Error

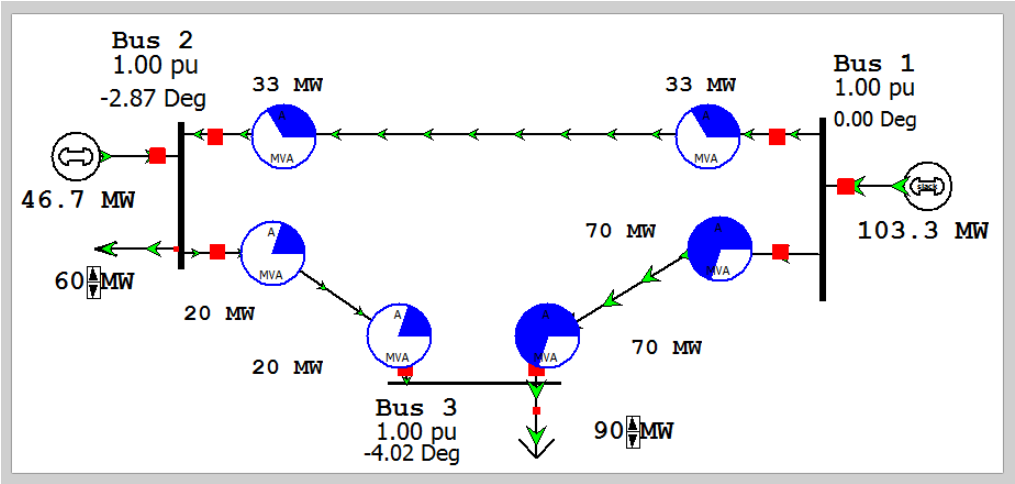


* AGC applied only to selected units

[18]

What is a Power Flow?

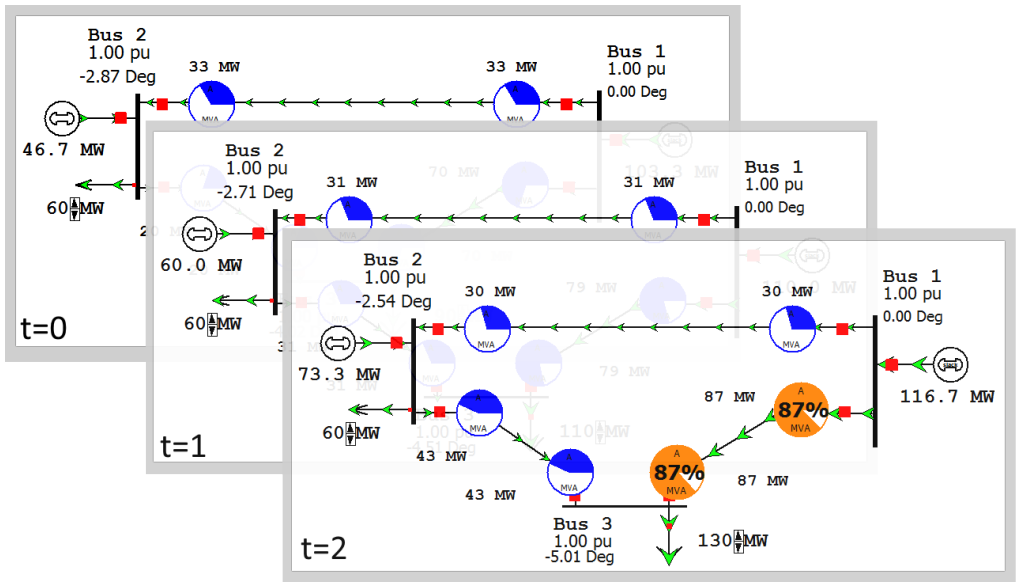
A steady state power system solution.



Software exists to solve power flows.
Power flows are not dynamic.

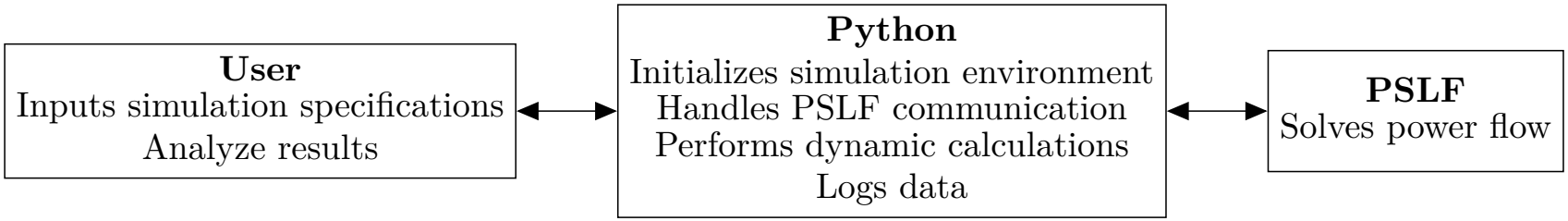
Time-Sequenced Power Flows?

Power flows arranged in sequence to give the illusion of time.



Software does not exist.

Custom Software



High Level Software Notes:

- Python and IronPython
- Advance Message Queueing Protocol
- Agent Based Modeling

Why use this method?

Allows for:

- Simplifications
- Greater access to data
- Customizable models in a modern programming language

So, what's happening?

Essentially:

- Executing computer simulations of the grid that are at least 10 minutes long.
- Simulation time steps are a sequence of power flows.
- Additional dynamic calculations are performed between each time step.

And why?

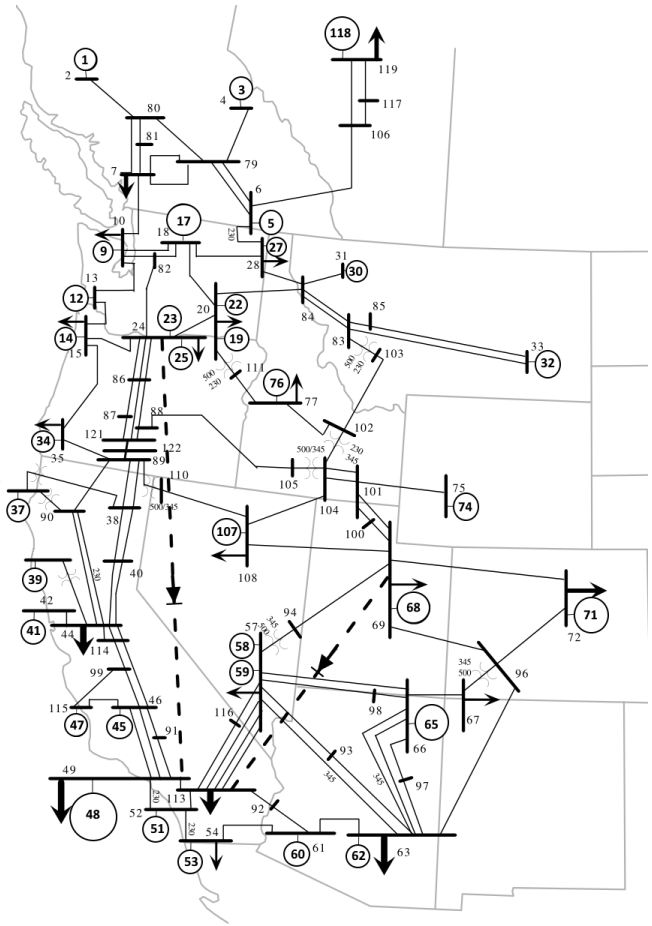
To study engineering problems involving:

- Long-term events (i.e. Wind Ramps)
- Multi-Area Power Interactions
  - Governor and AGC interaction
  - Governor and AGC settings
- Ways to reduce machine effort while meeting reliability standards.

Validation Software Model

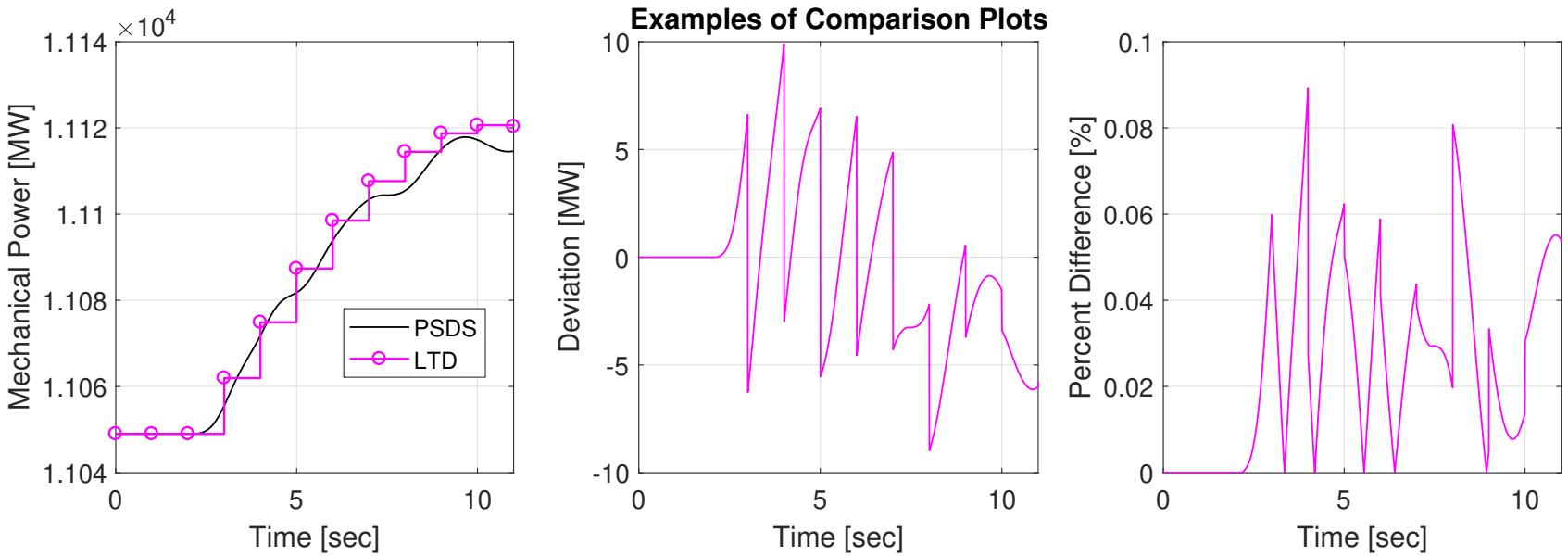
miniWECC

- 34 Generators
- 104 Lines
- 3 Areas
- 23 Loads
- 120 Buses



[13]

Plot Explanation

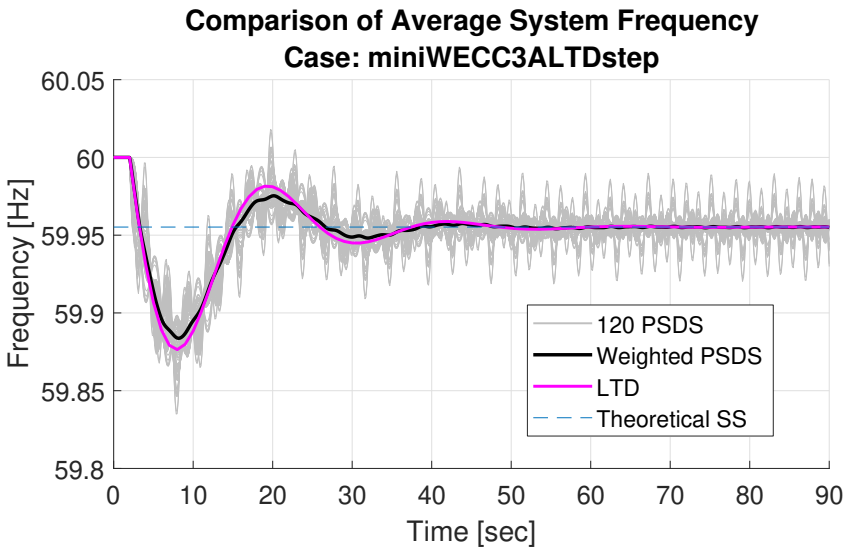


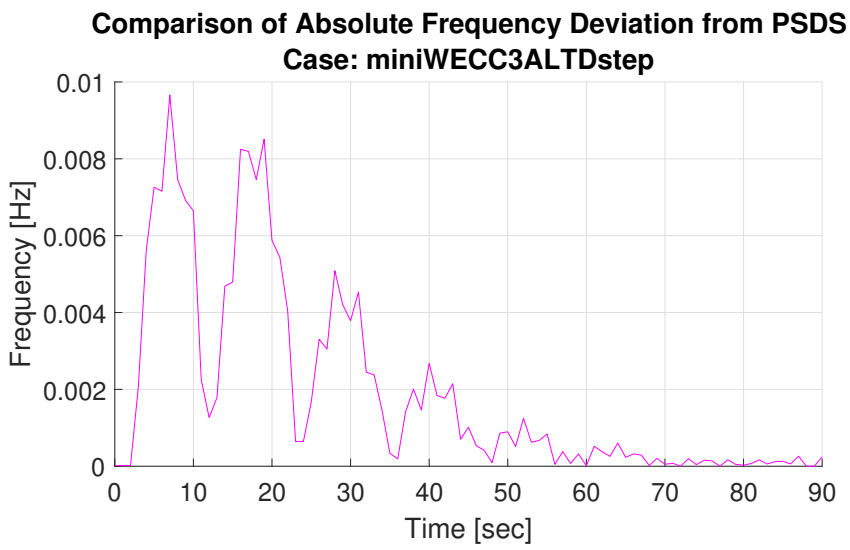
$$\text{PSDS}_{data} - \text{LTD}_{data} = \text{Deviation}_{data}$$

$$\%_{diff} = \frac{|x - y|}{\frac{x+y}{2}} * 100\%$$

Step Perturbance Validation

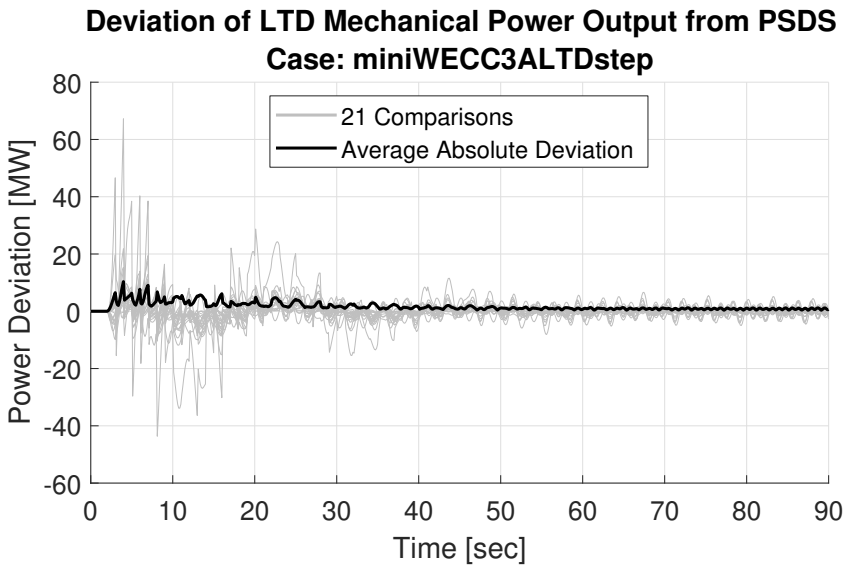
400 MW Load Step Frequency Comparison

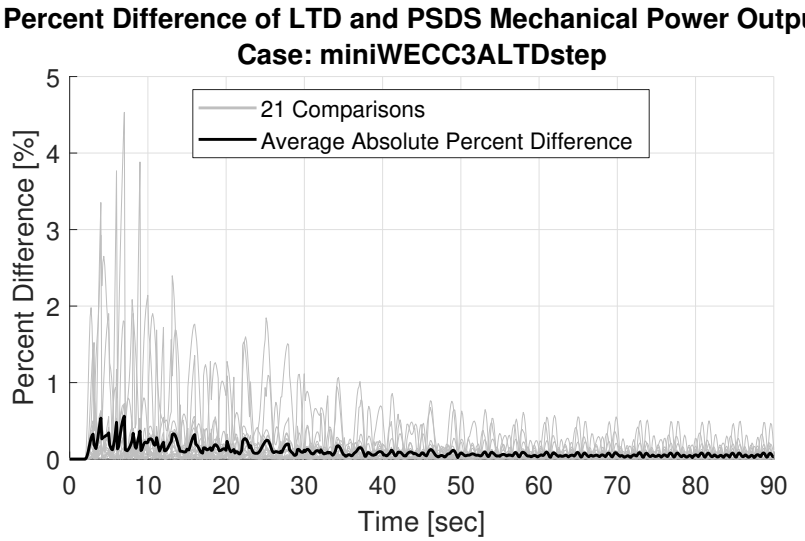




Step Perturbance Validation

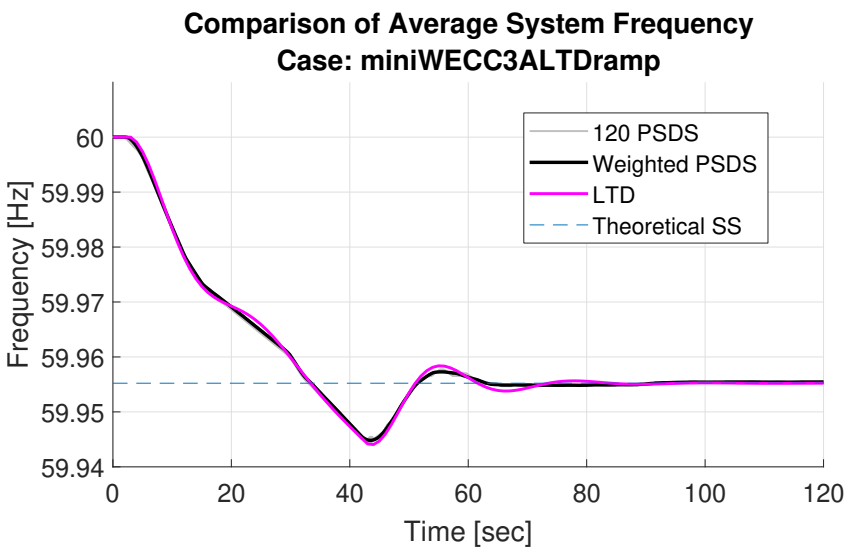
400 MW Load Step Mechanical Power Comparison

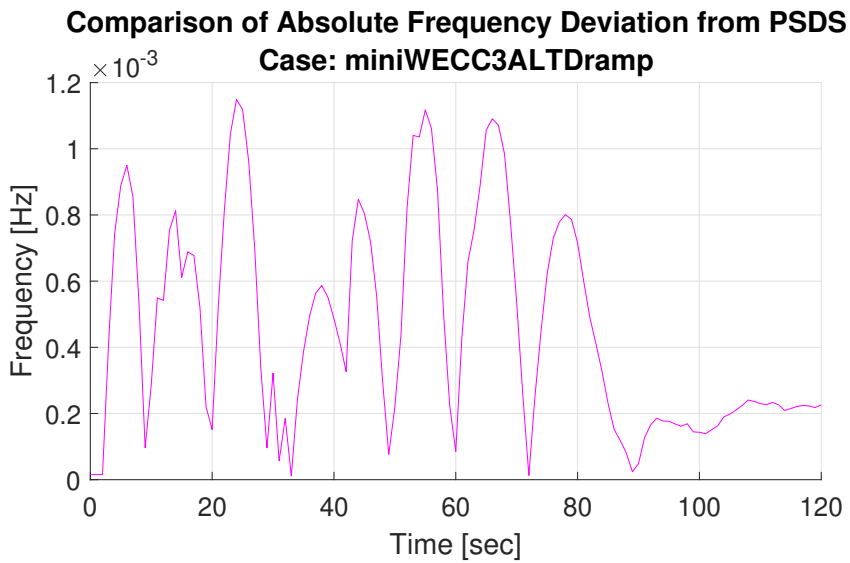




Ramp Perturbance Validation

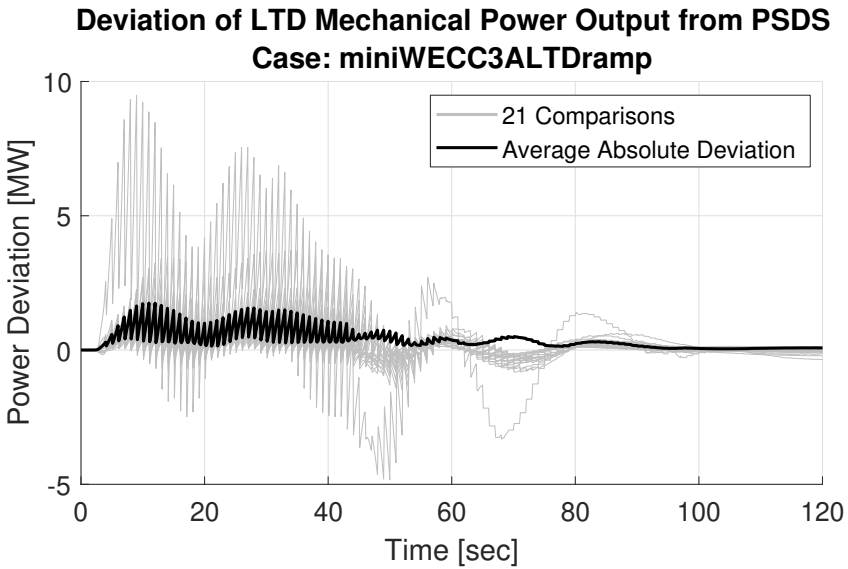
20 second 400 MW Load Ramp Frequency Comparison

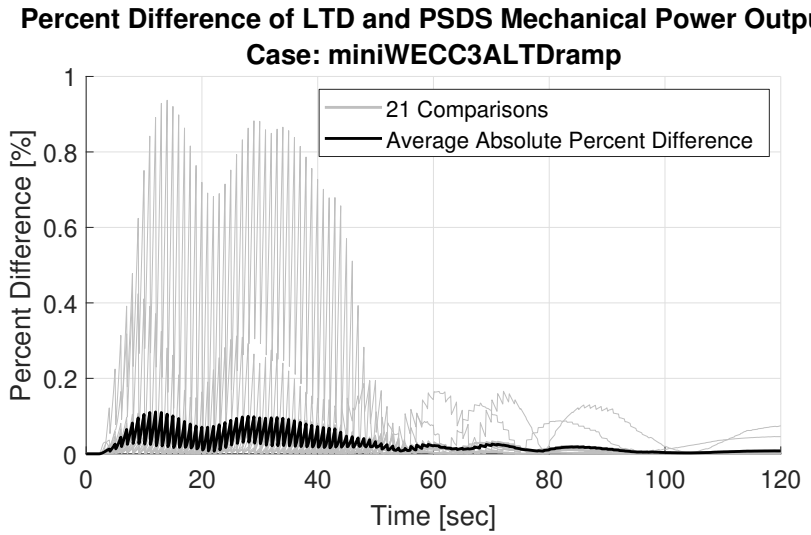




Ramp Perturbance Validation

20 second 400 MW Load ramp Mechanical Power Comparison

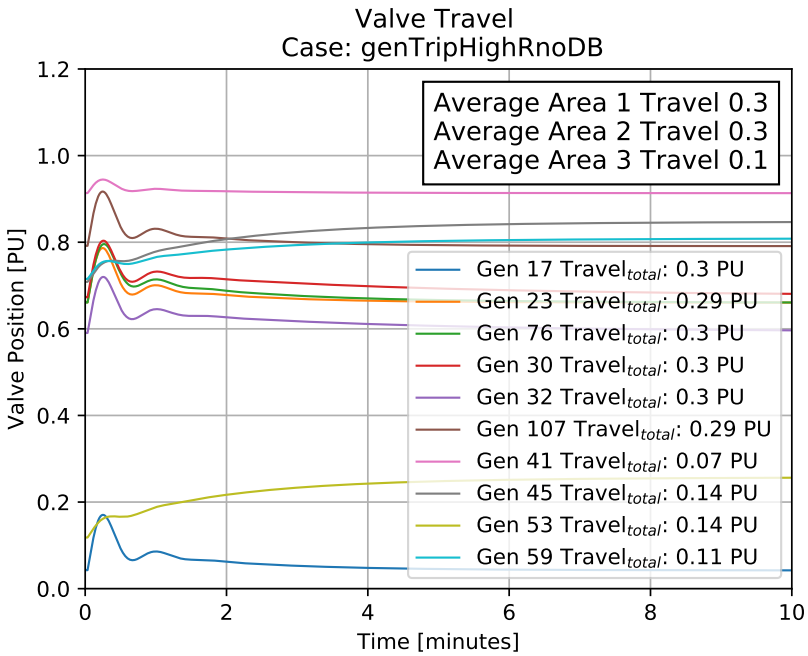




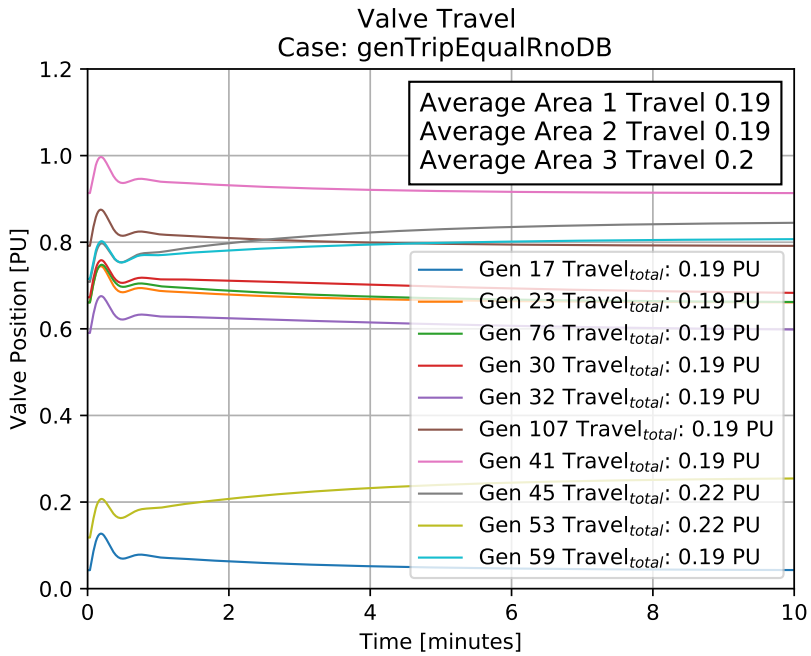
Area Droop and Valve Travel

Perturbance: -1500 MW power step in Area 3 at t=2

Area 3 droop = 0.2



Area 3 droop = 0.05



Current Conclusions

- Software (PSLTDSim) output appears valid for tested systems.
- Governor droop in one area affects how other areas respond.
- Step deadband may increase valve travel.

Continuing Work

- Experiments with AGC and 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] R. W. Cummings, W. Herbsleb, and S. Niemeyer. (2010), Generator governor and information settings webinar, North American Electric Reliability Corporation, [Online]. Available: https://www.nerc.com/files/gen-governor-info-093010.pdf.

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

References II

[6] (2017). Ercot-interconnection_branded.jpg, ERCOT, [Online]. Available: http://www.ercot.com/news/mediakit/maps.

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

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

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

[10] 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.

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

References III

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

[13] R. Hallett, "Improving a transient stability control scheme with wide-area synchrophasors and the microwecc, a reduced-order model of the western interconnect," Master's thesis, Montana Tech, 2018.

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

[15] J. JMesserly. (2008), Electricity_grid_simple-_north_america.svg, United States Department of Energy, [Online]. Available: https://commons.wikimedia.org/wiki/File:Electricity_grid_simple-_North_America.svg.

References IV

[16] (2019). July2019map.png, U.S. Energy Information Administration, [Online]. Available: https://www.eia.gov/electricity/data/eia860m/.

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

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

[19] 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.

References V

[20] (2004). Montana electric transmission grid: Operation, congestion, and issues, DEQ, [Online]. Available: https://leg.mt.gov/content/publications/Environmental/2004deq_energy_report/transmission.pdf.

[21] P. W. Parfomak, "Physical security of the u.s. power grid: High-voltage transformer substations," Congressional Research Service, 2014.

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

[23] 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 VI

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

[25] N. R. Subcommittee, “Balancing and frequency control,” North American Electric Reliability Corporation, 2011.

[26] ——,“Bal-001-tre-1 primary frequency response in the ercot region,” North American Electric Reliability Corporation, 2016.

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

[28] (2019). U.s. electric system operating data, U.S. Energy Information Administration, [Online]. Available: https://www.eia.gov/realtime_grid/.

References VII

[29] (2019). U.s. energy mapping system, U.S. Energy Information Administration, [Online]. Available: https://www.eia.gov/state/maps.php?v=Electricity.

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