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

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Montana Technological University - Master's Thesis Research Project

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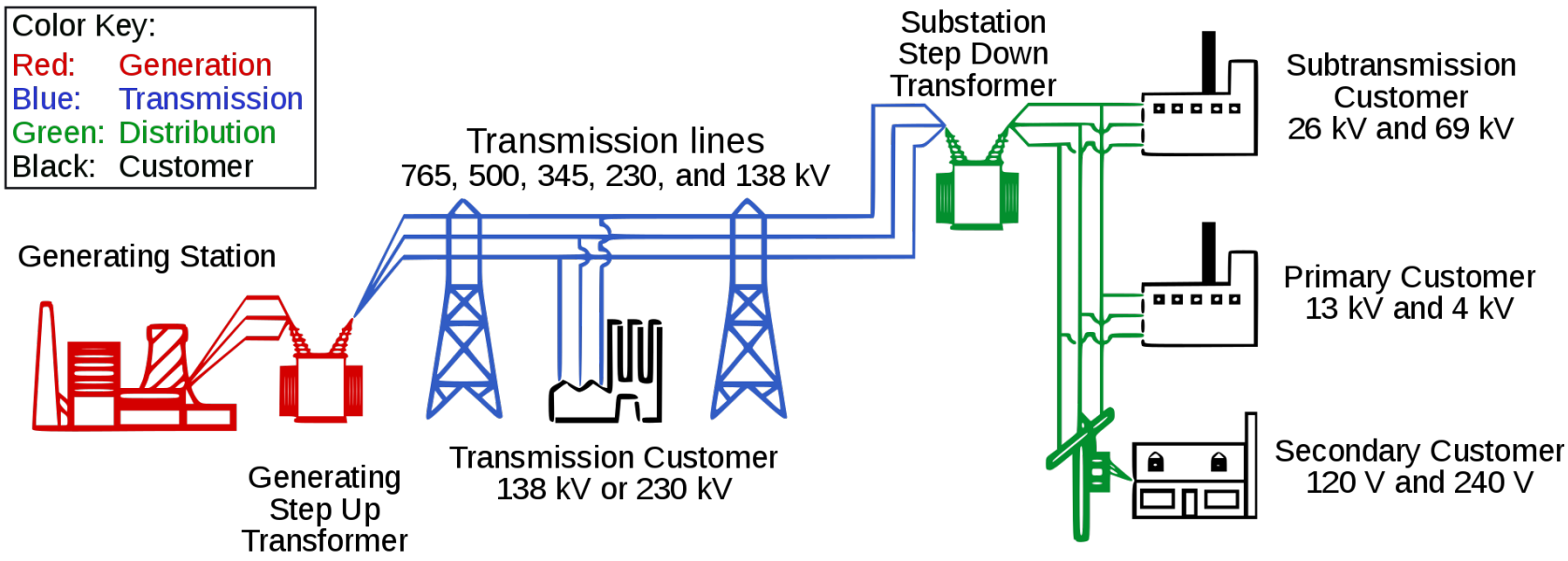
What is a Power System?

Electrical supply connected to demand.



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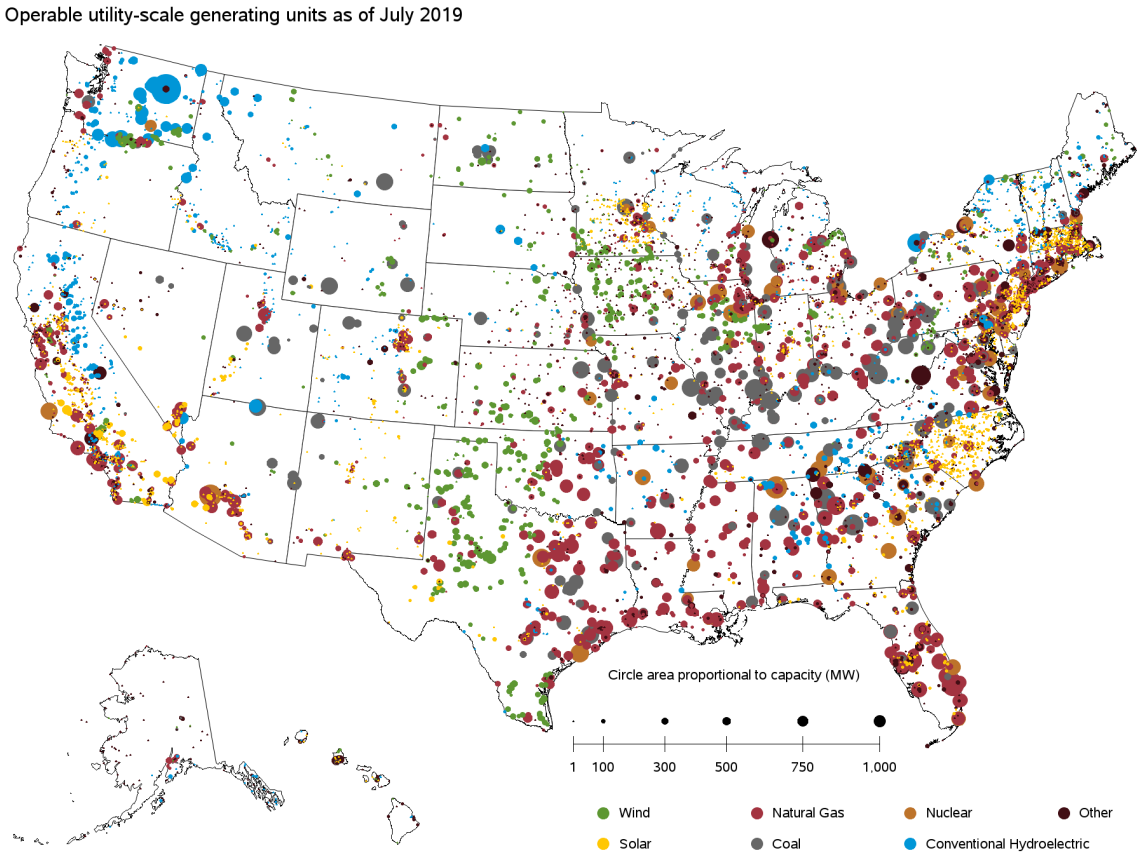
Research focus on transmission system.

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.'

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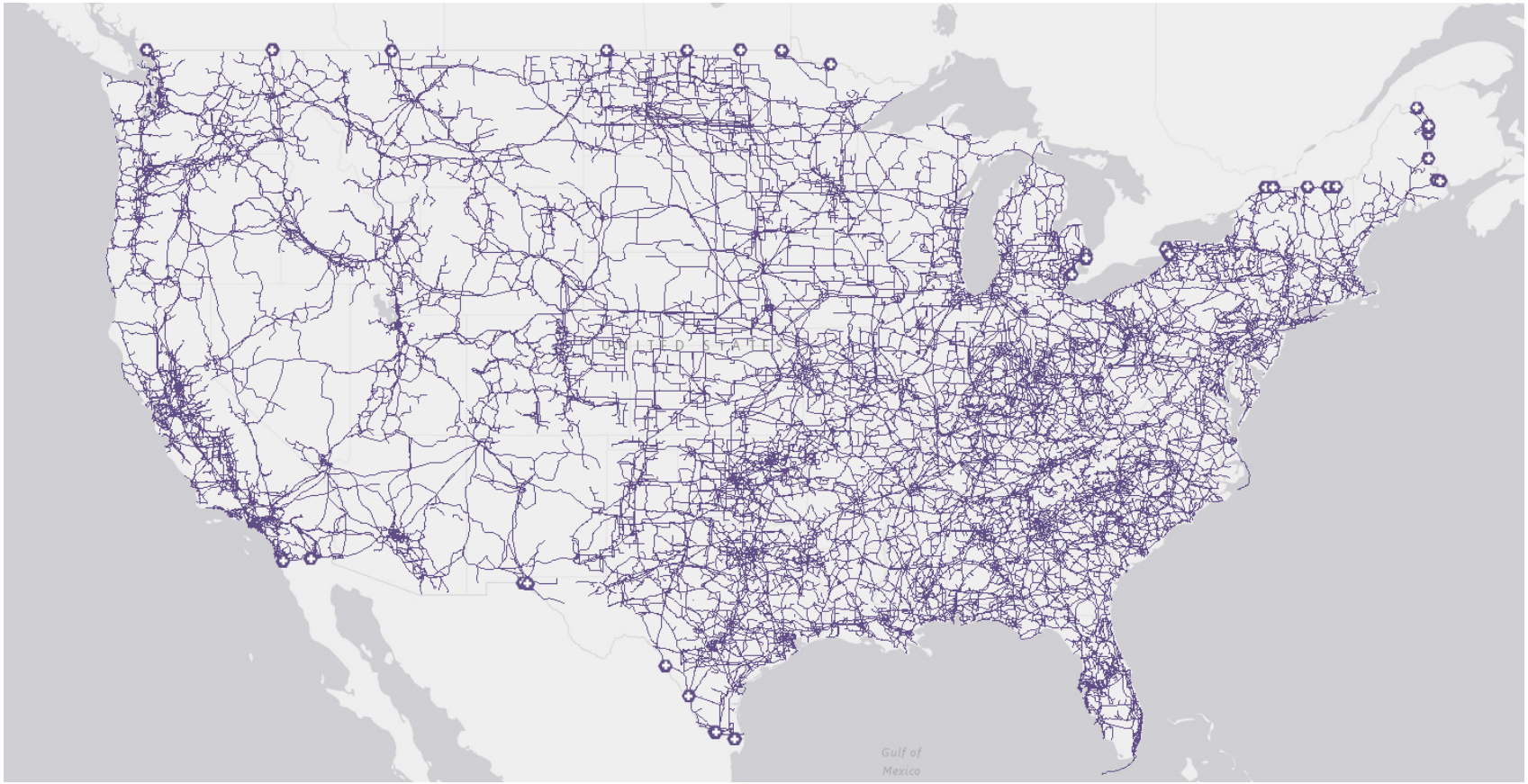
U.S. Electric Transmission Lines



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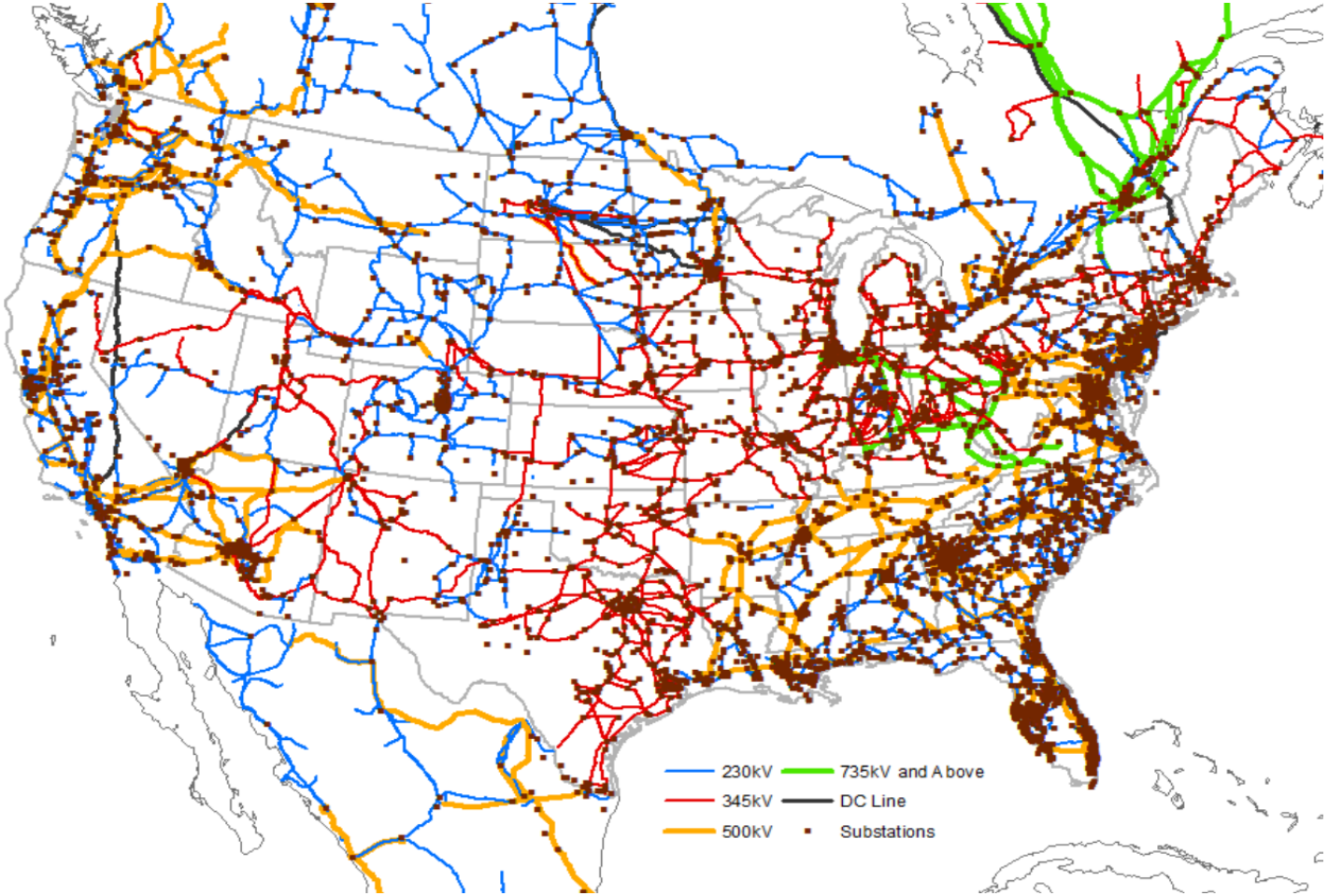
Electric Transmission Lines



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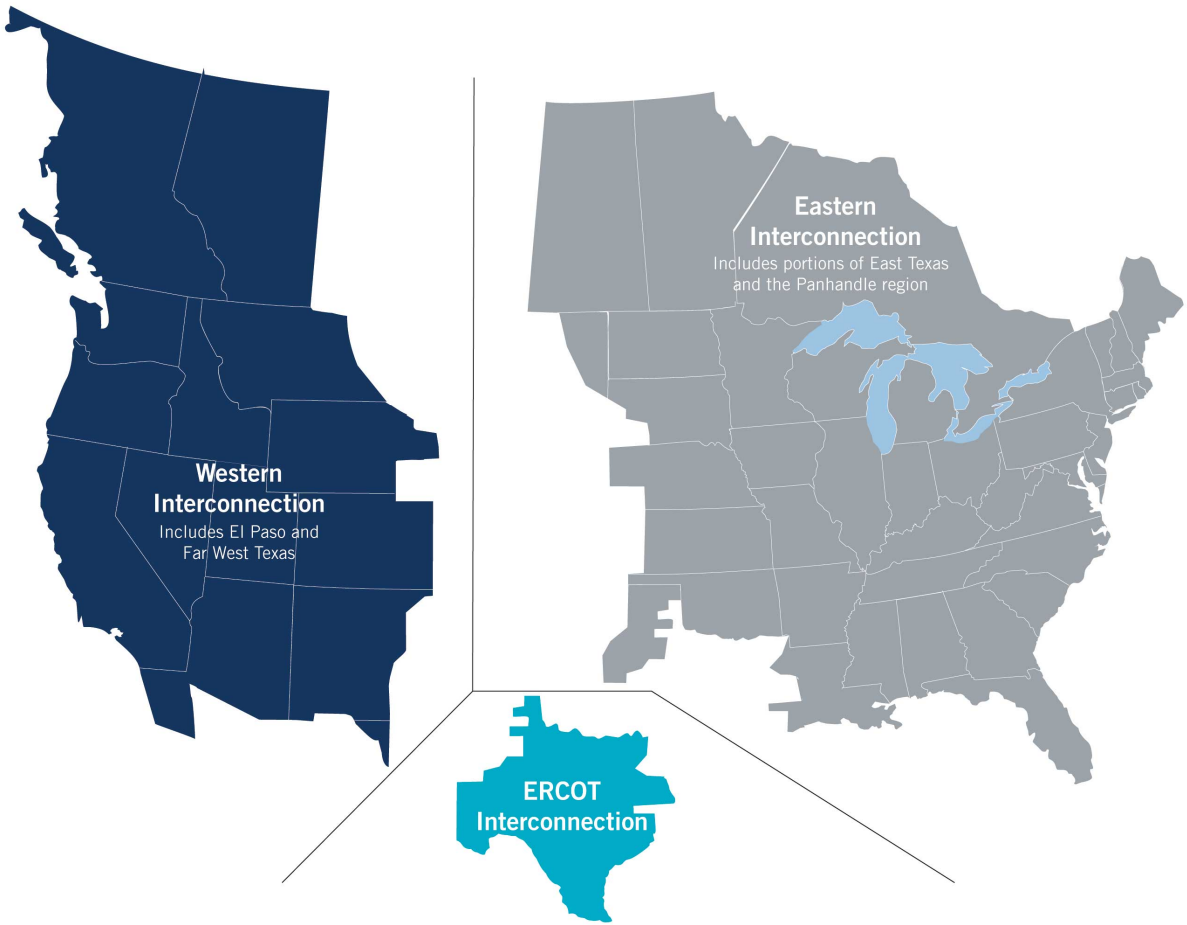
Interconnections



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Industry Software Model

WECC Model (GE PSLF)

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

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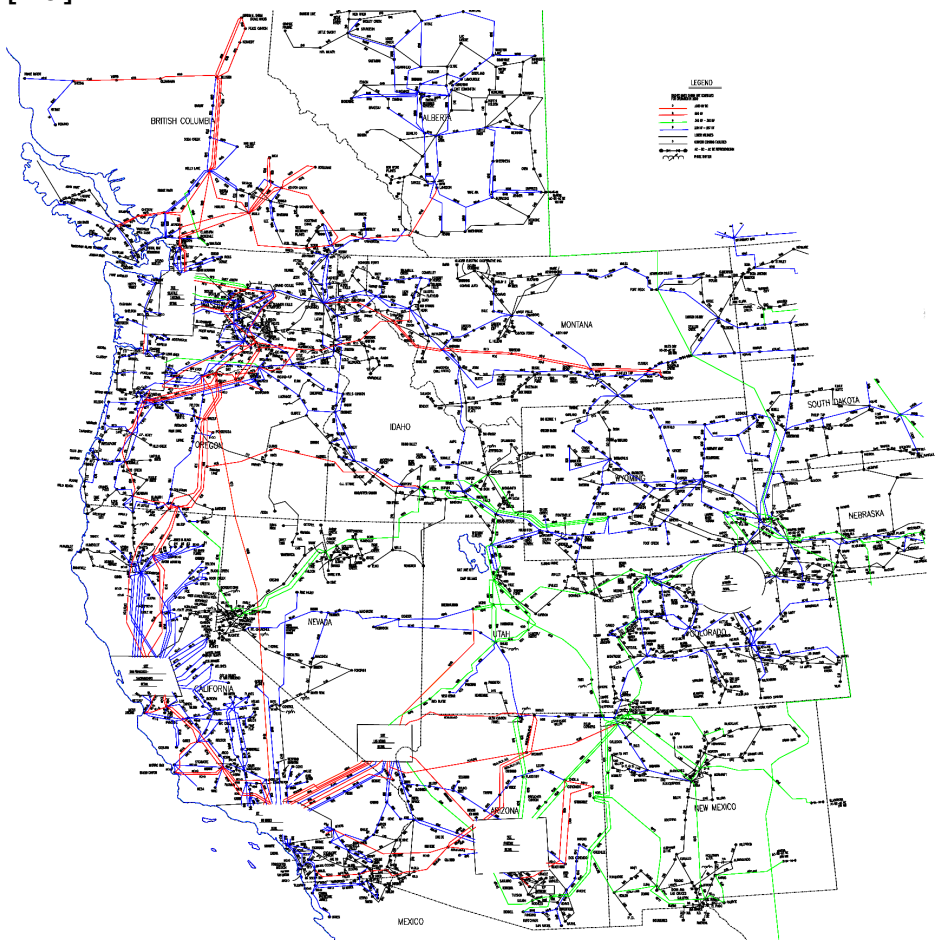
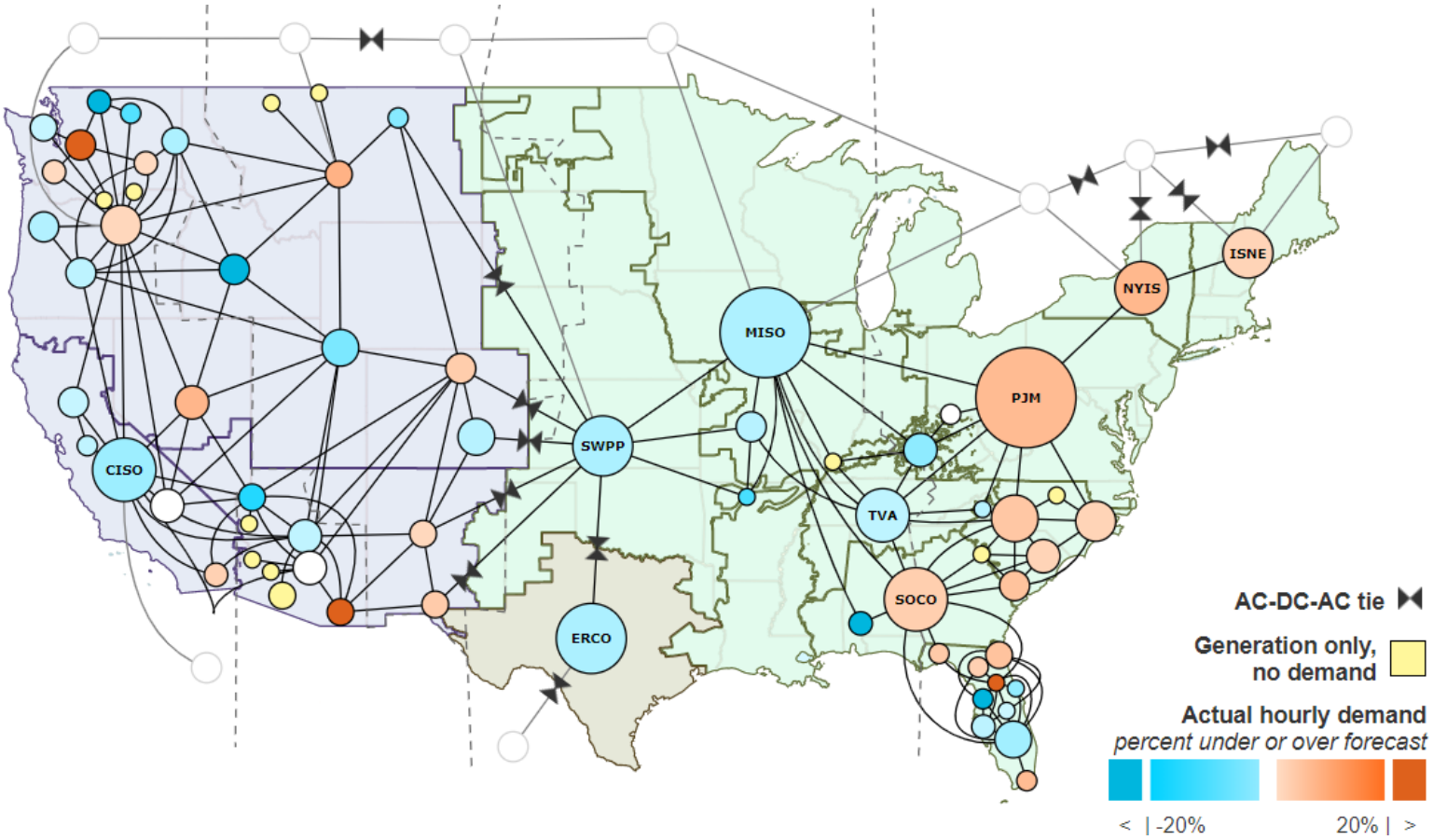


‘People in Charge’

- **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)



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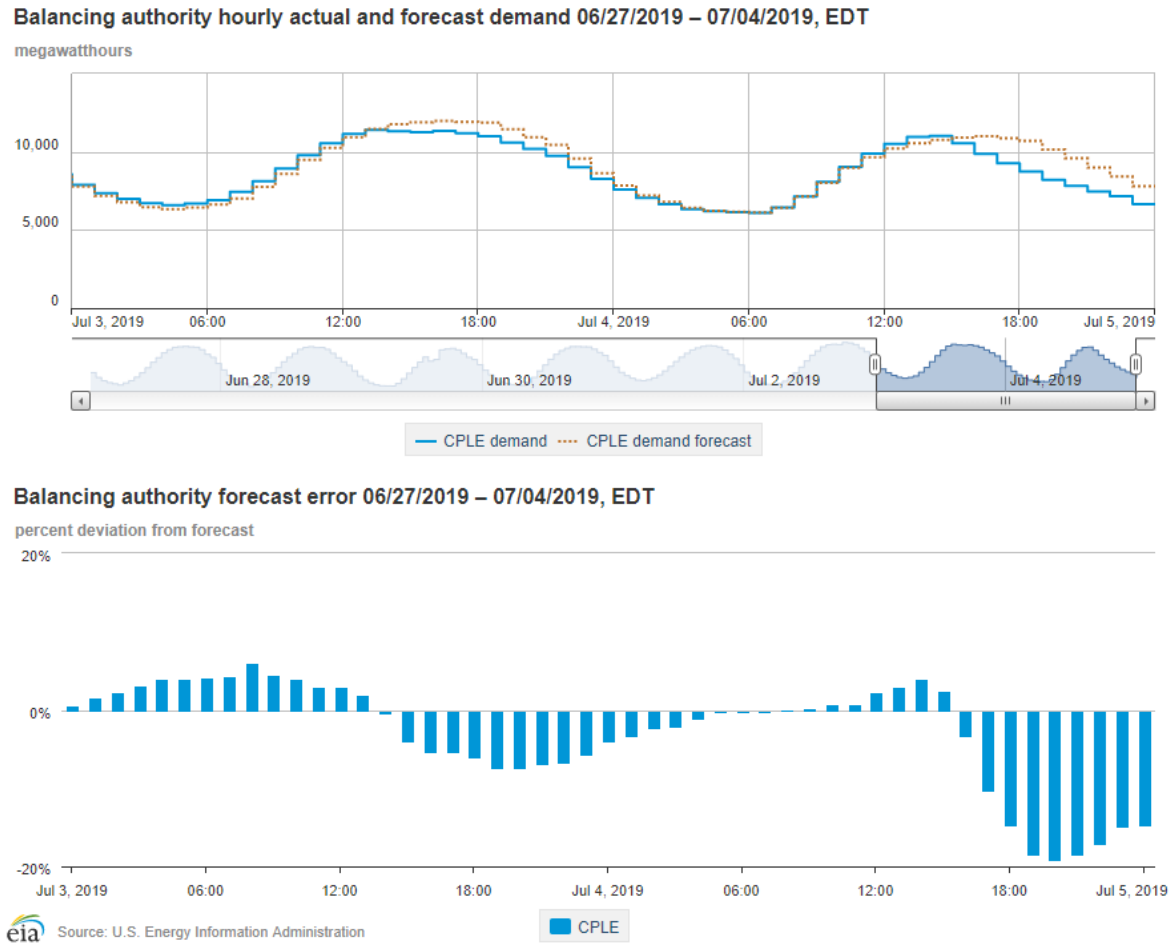
BA Action - Forcasting



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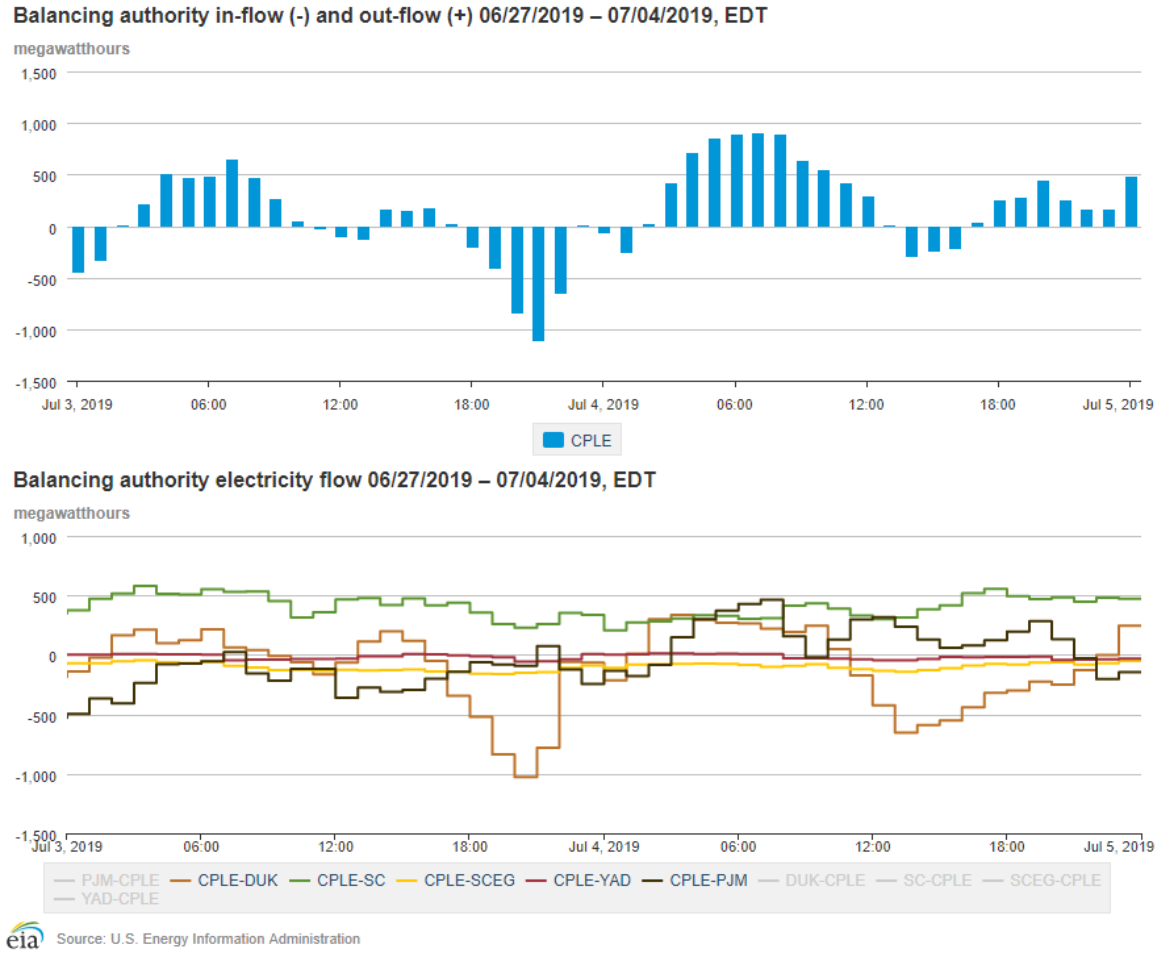
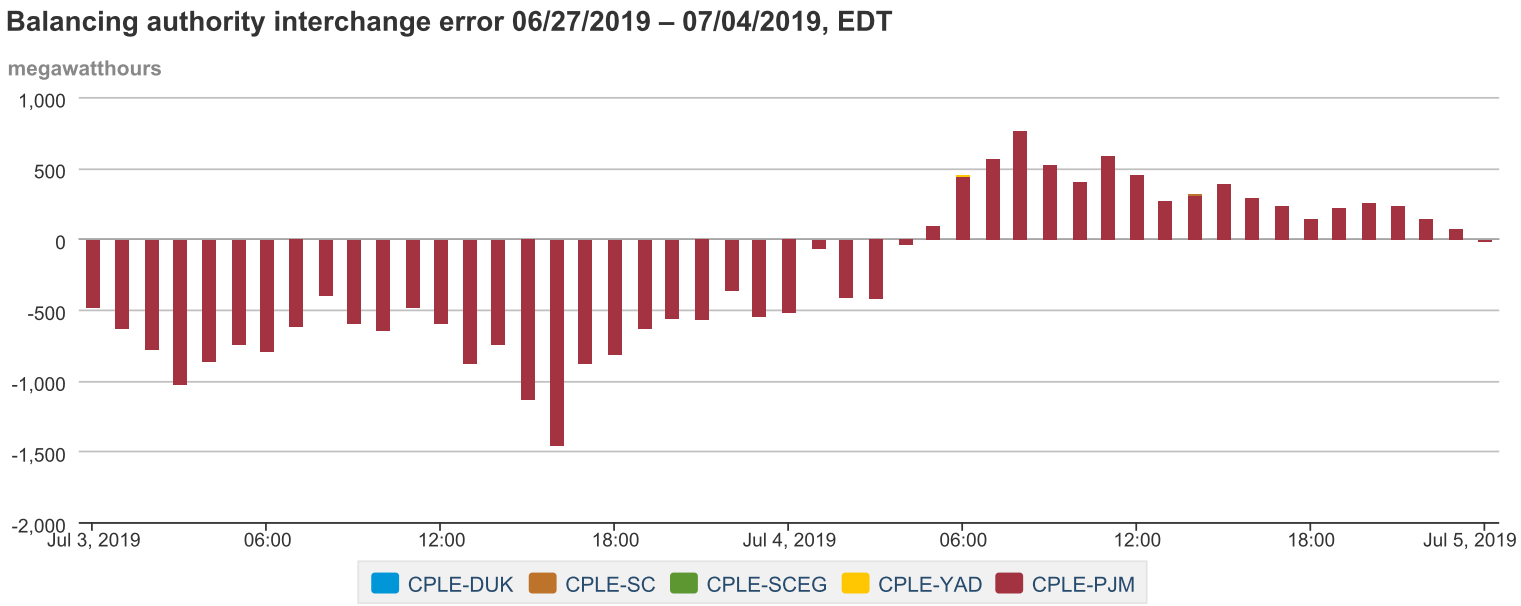
BA Action - Interchange



[28]

BA Action - Error Tracking



eia Source: U.S. Energy Information Administration

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Area Control Error = Interchange Error + Frequency Error (ACE)

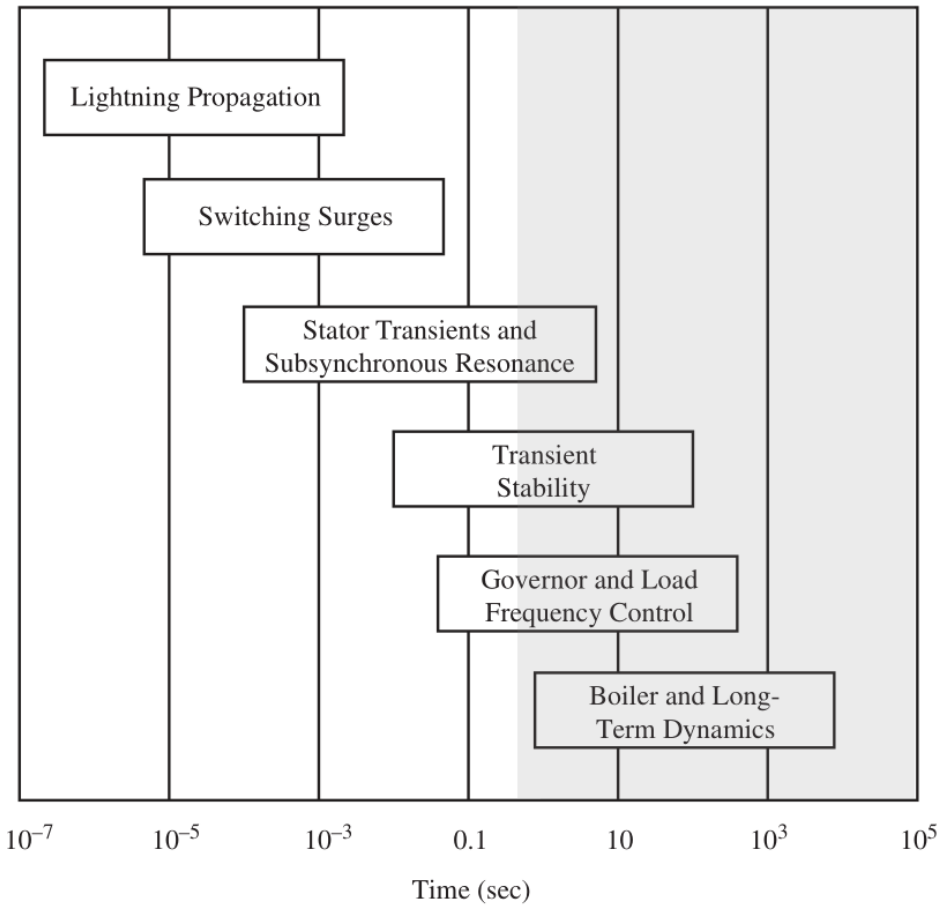
What is Dynamic Simulation?

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?



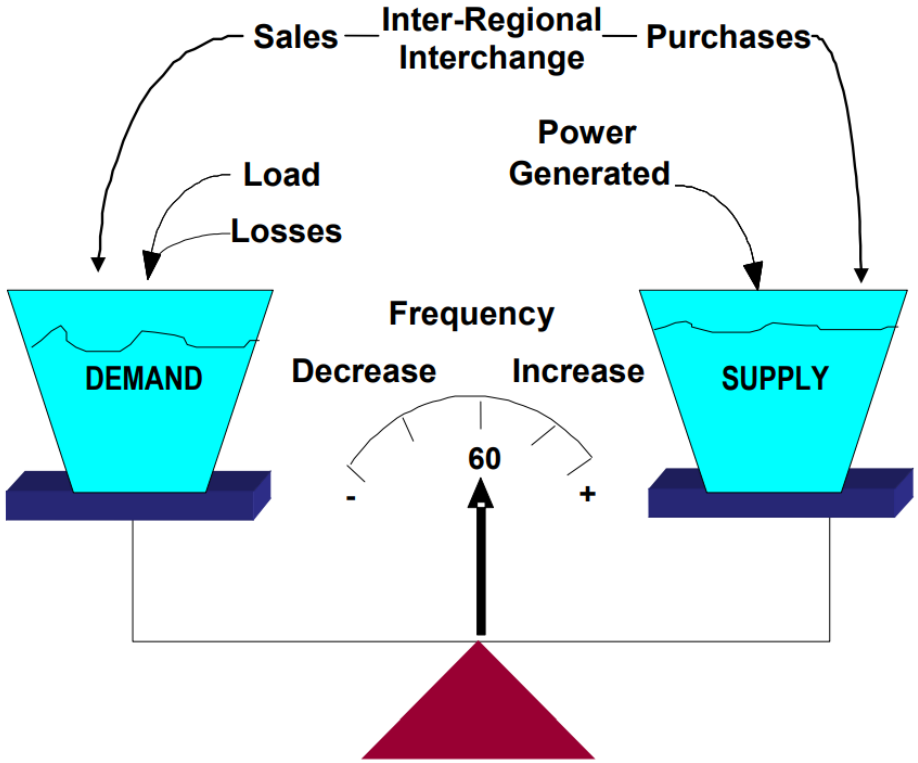
[23]

- 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.

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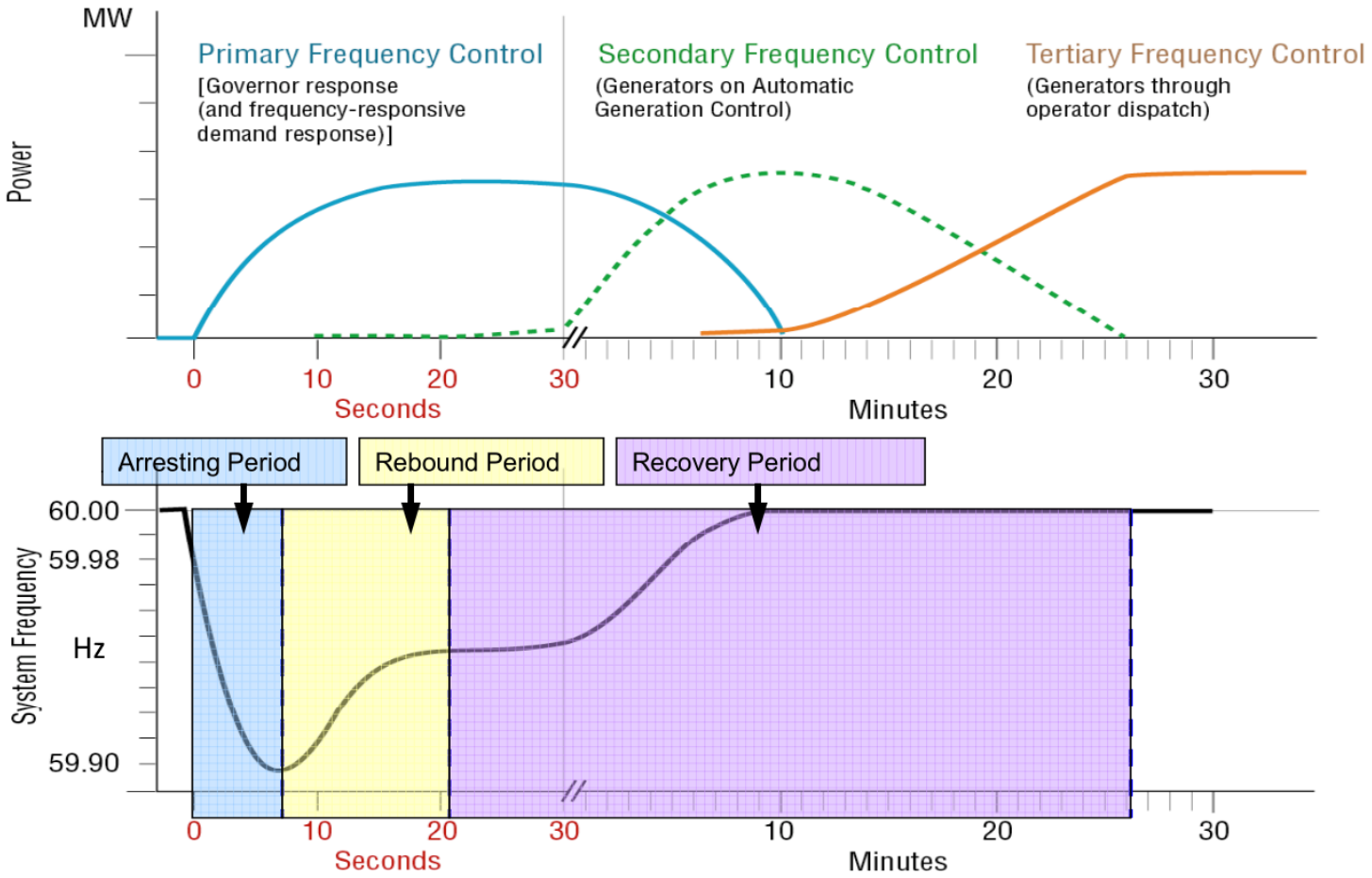
Load and losses always changing.

Automatic Controls



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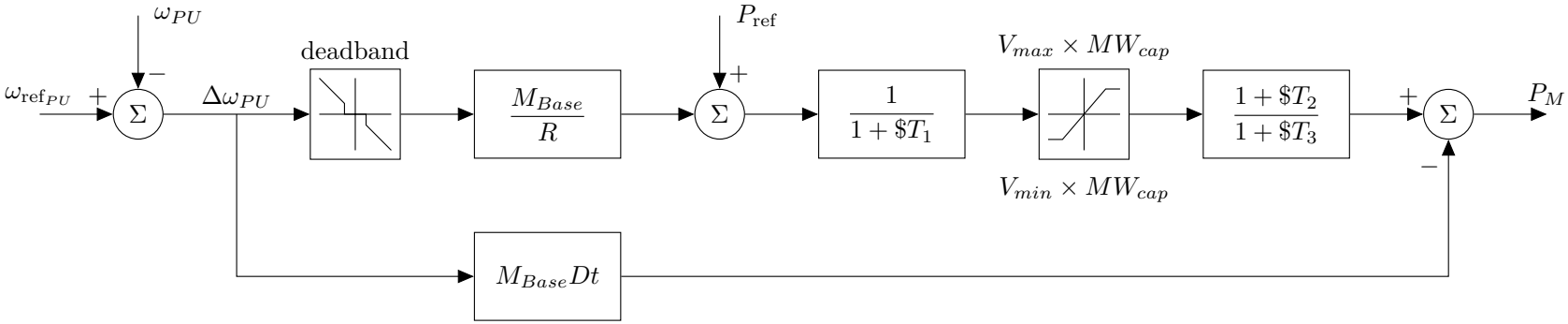
Turbine Speed Governors

Primary Control

Purpose: Adjust turbine mechanical power to arrest frequency decline.

Dynamic Variable: Fuel Valve Position

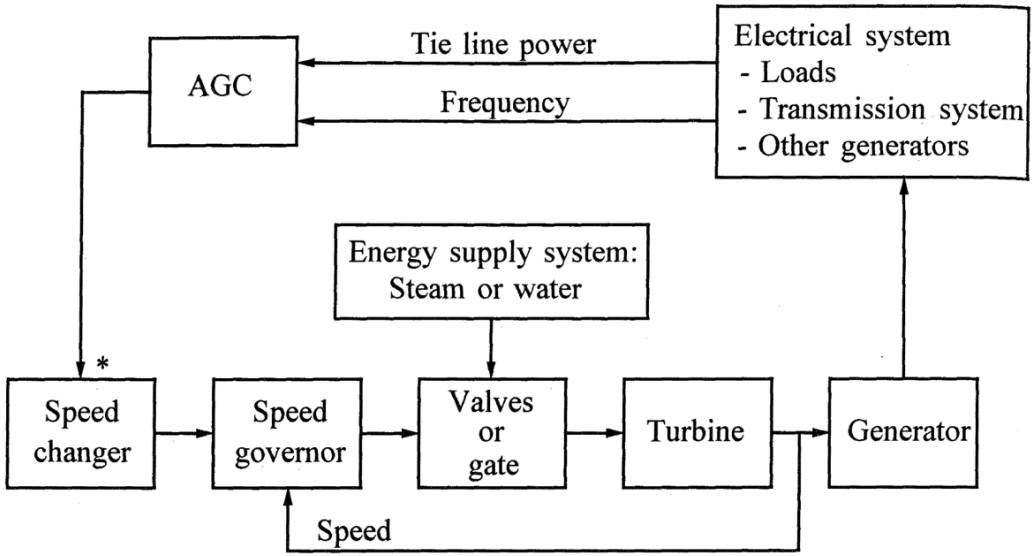


Automatic Generation Control (AGC)

Secondary Control

Purpose: Eliminate Area Control Error

Dynamic Variable: Area Control Error



* AGC applied only to selected units

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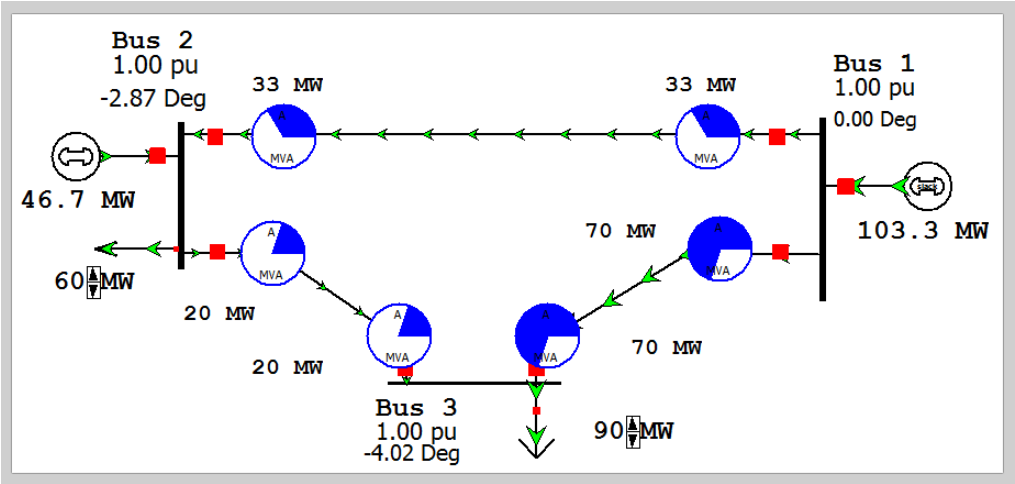
What is a Power Flow?

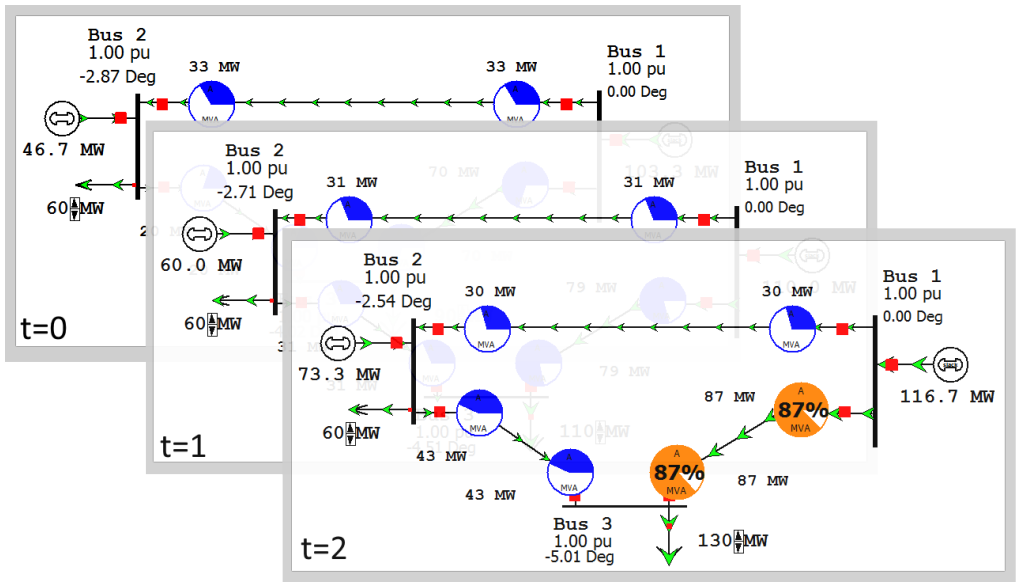
A steady state power system solution.



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

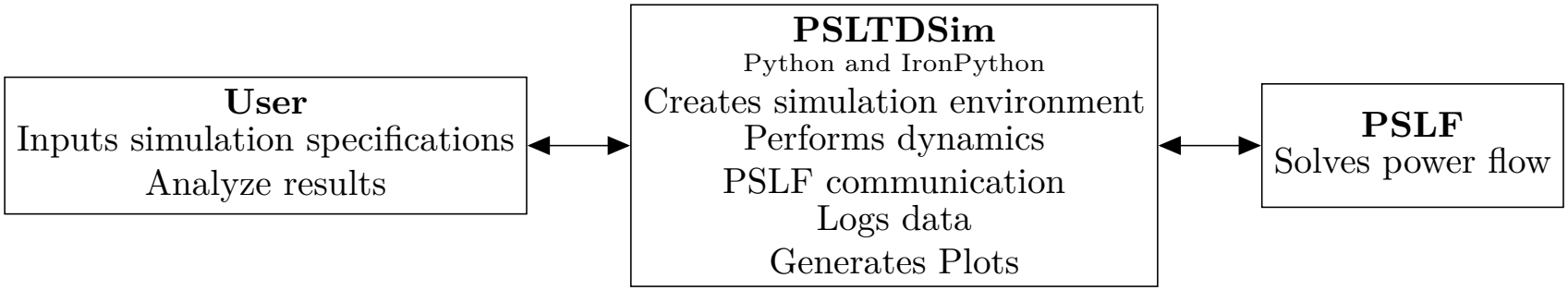
Time-Sequenced Power Flows?

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:

- Appropriate detail for time frame
- Simplifications and Assumptions
- 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 dynamics of interest are performed between each time step.

And why?

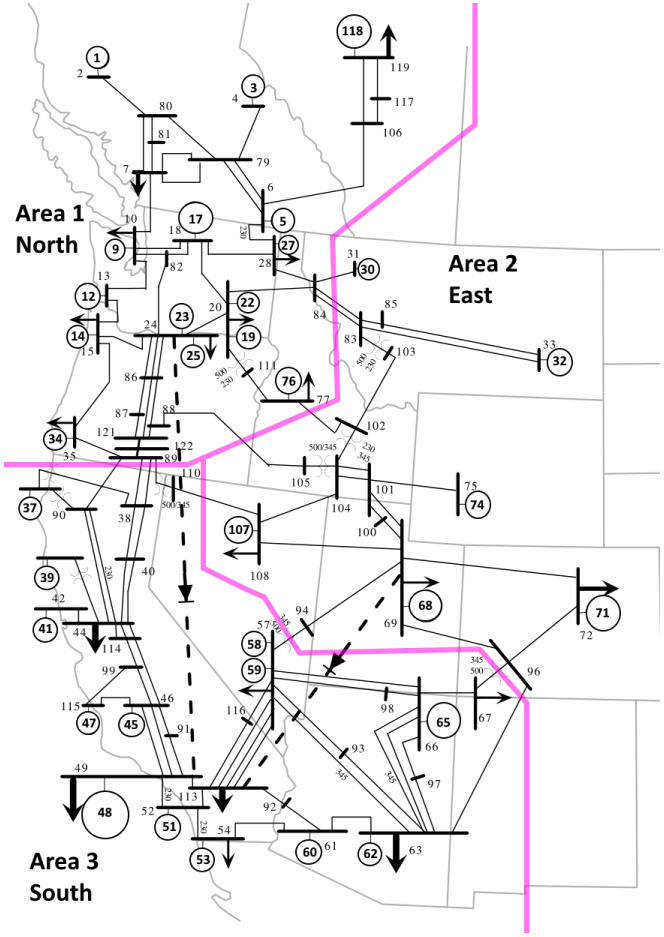
To study engineering problems involving:

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

Validation Software Model

miniWECC

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



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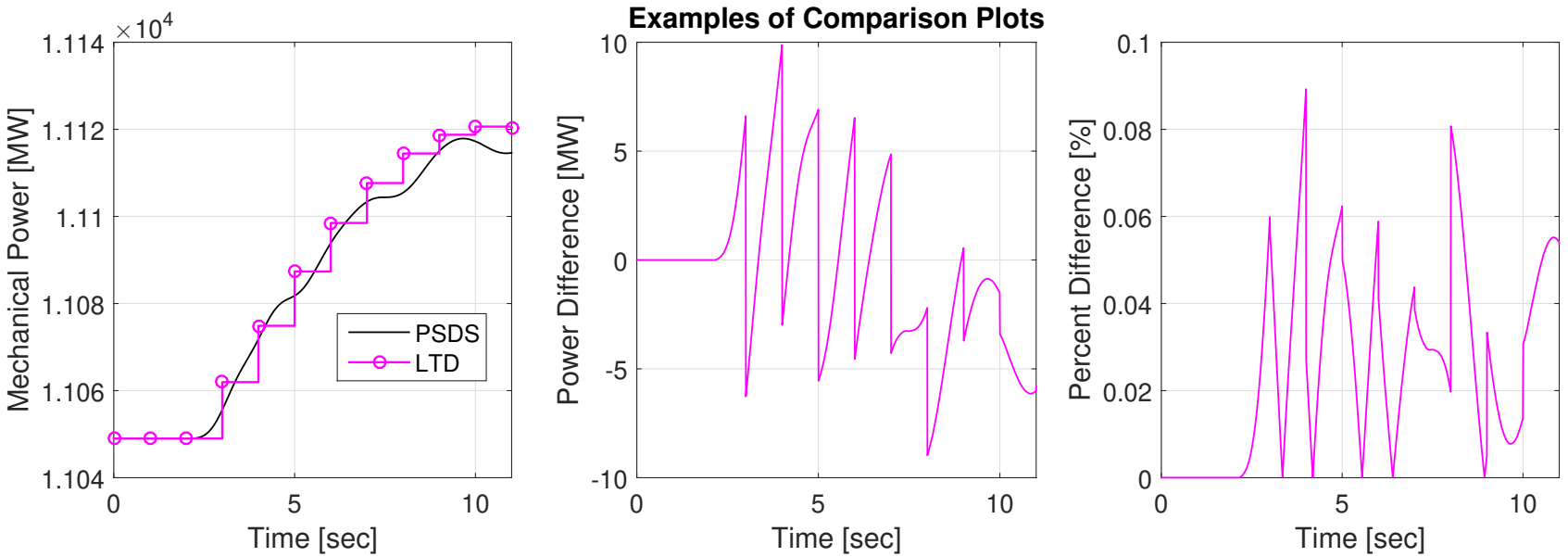
Plot Explanation

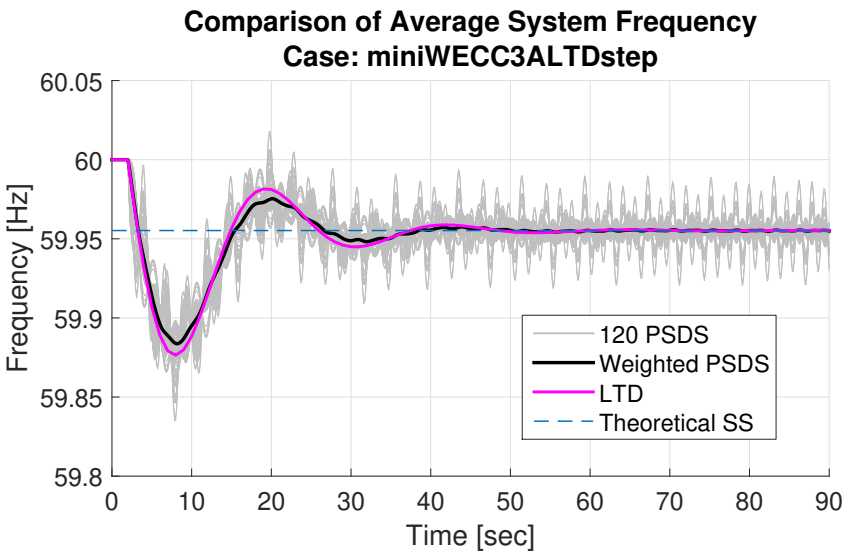


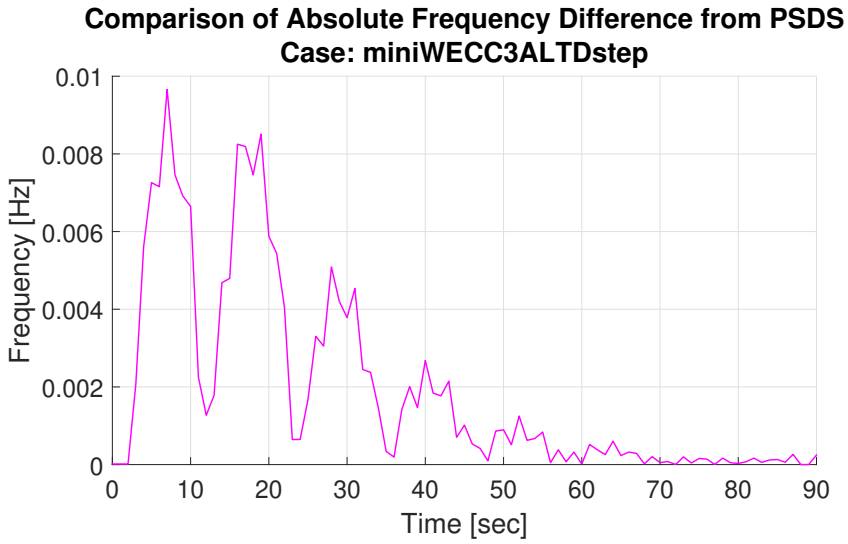
$$\text{PSDS}_{data} - \text{LTD}_{data} = \text{Difference}_{data}$$

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

Step Perturbance Validation

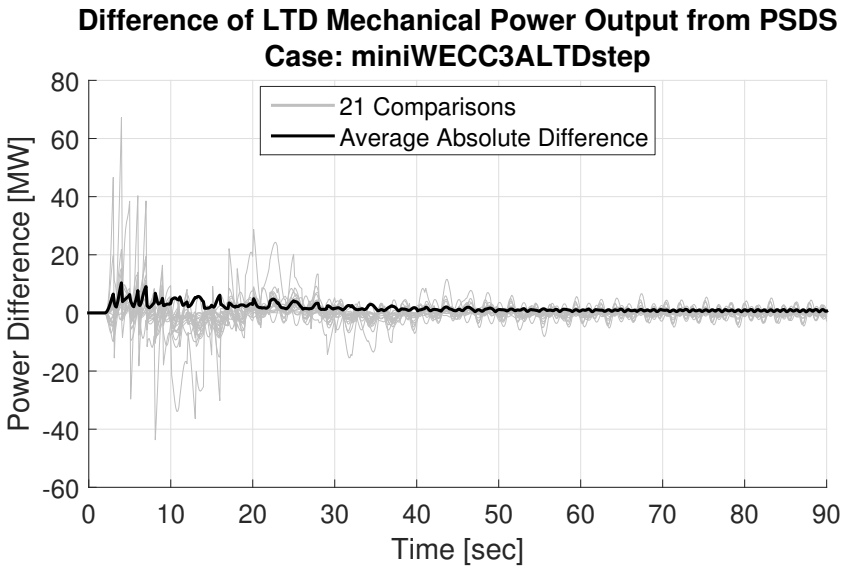
400 MW Load Step Frequency Comparison

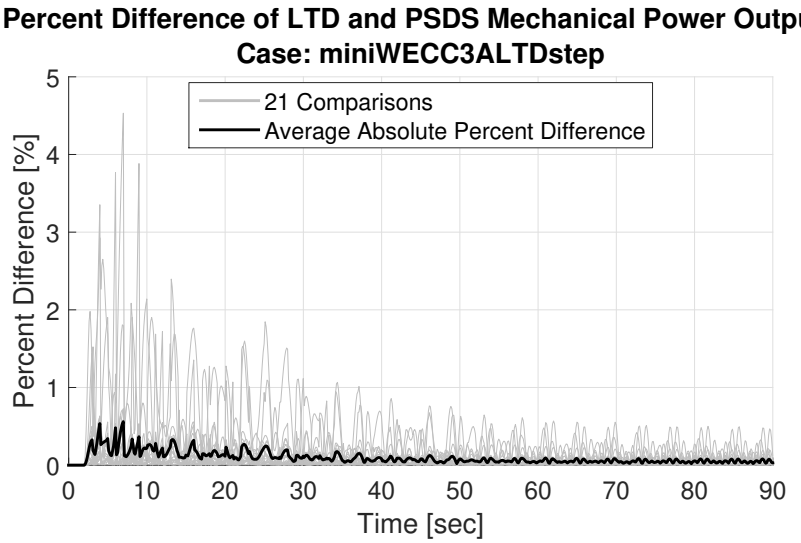




Step Perturbance Validation

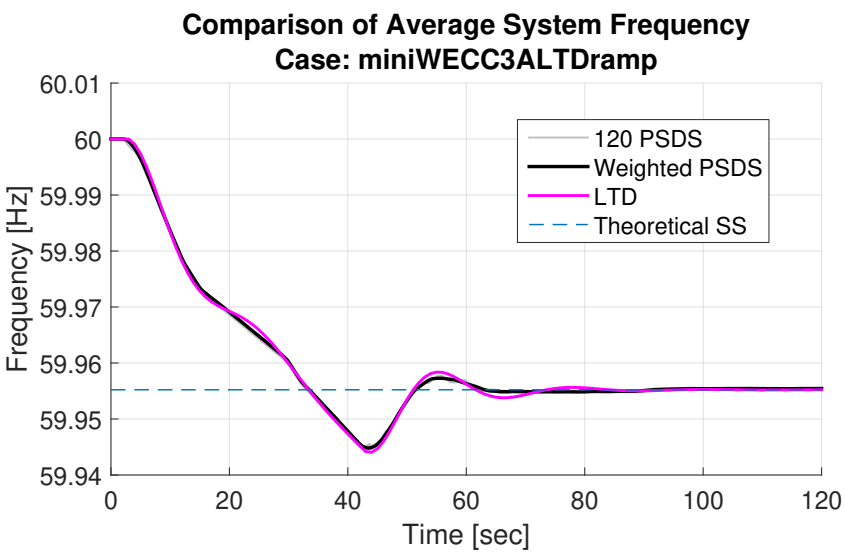
400 MW Load Step Mechanical Power Comparison

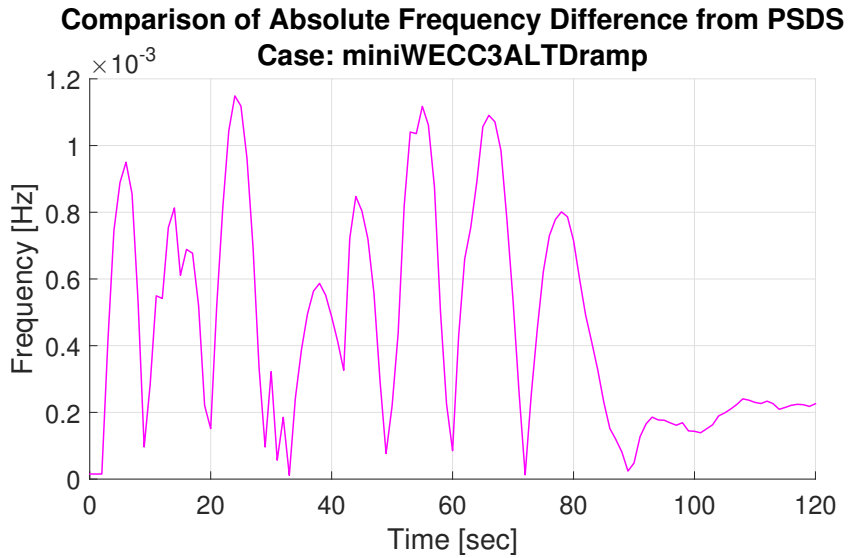




Ramp Perturbance Validation

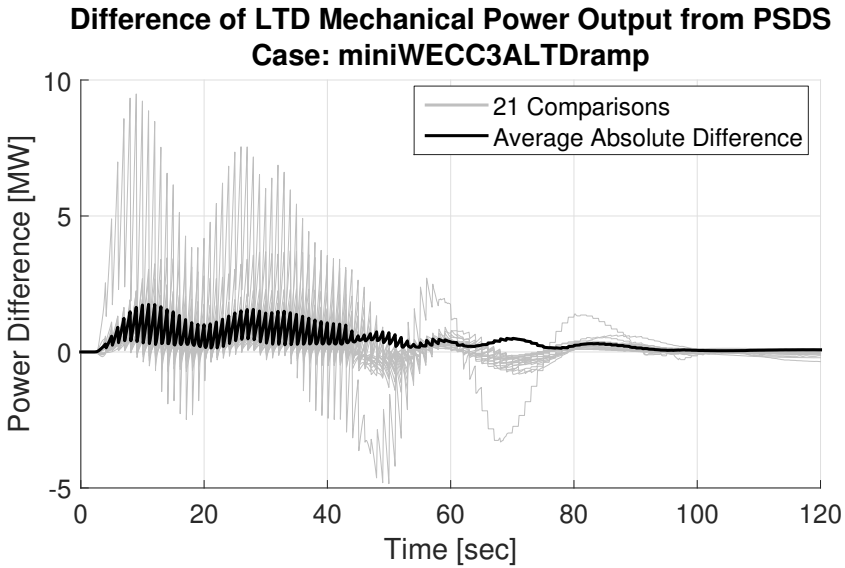
20 second 400 MW Load Ramp Frequency Comparison

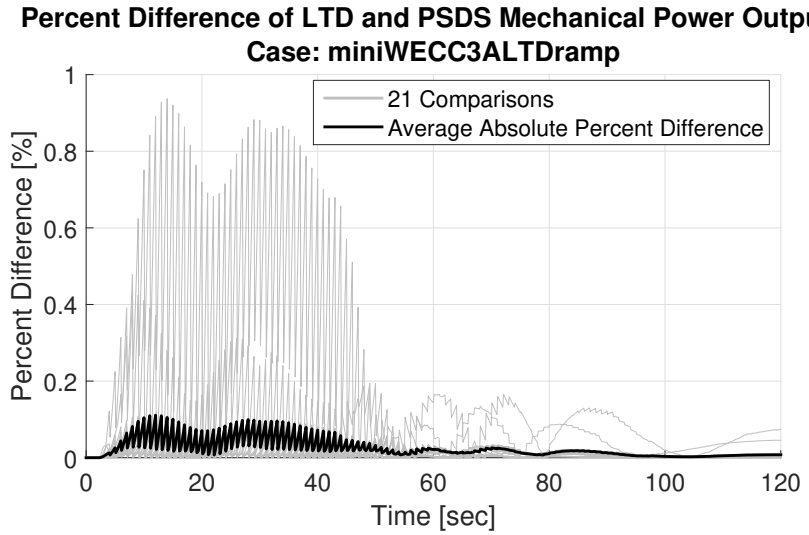




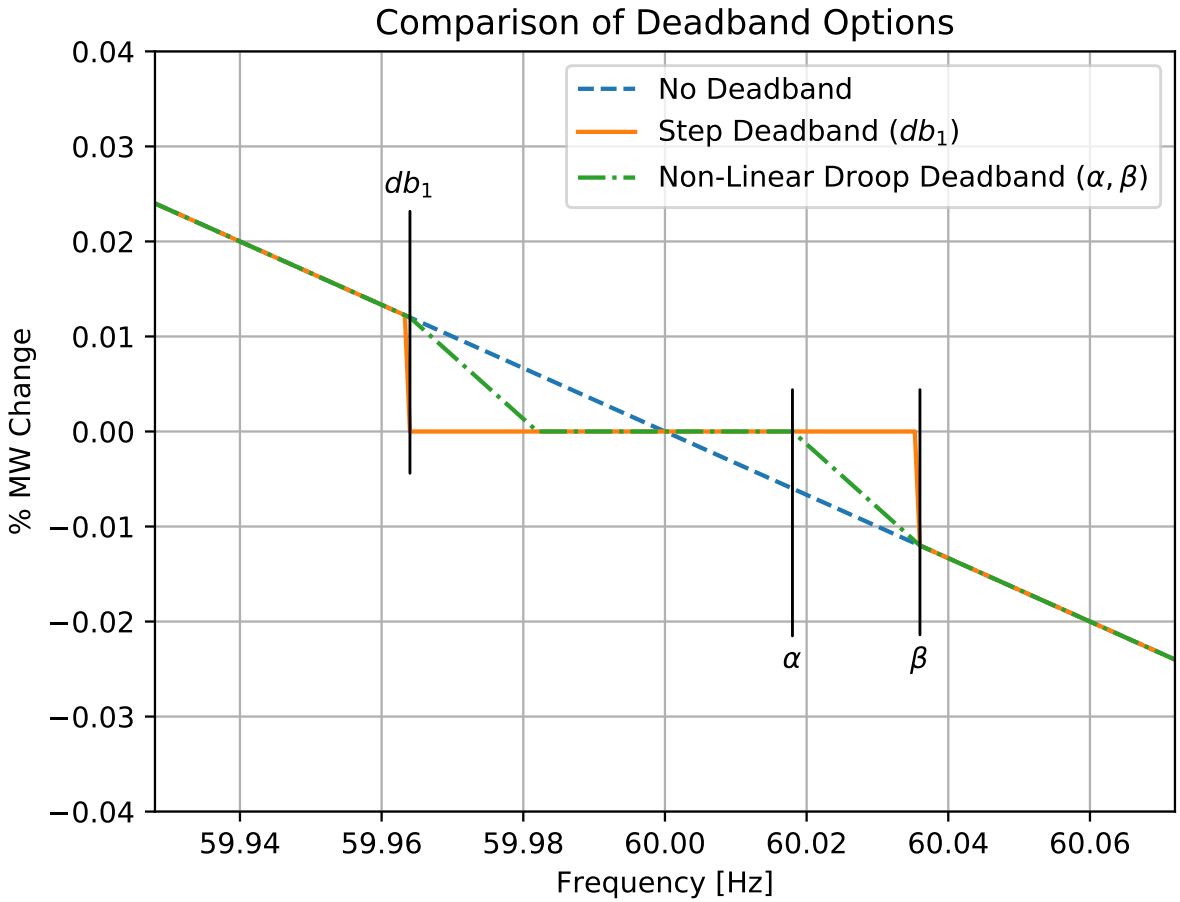
Ramp Perturbance Validation

20 second 400 MW Load ramp Mechanical Power Comparison



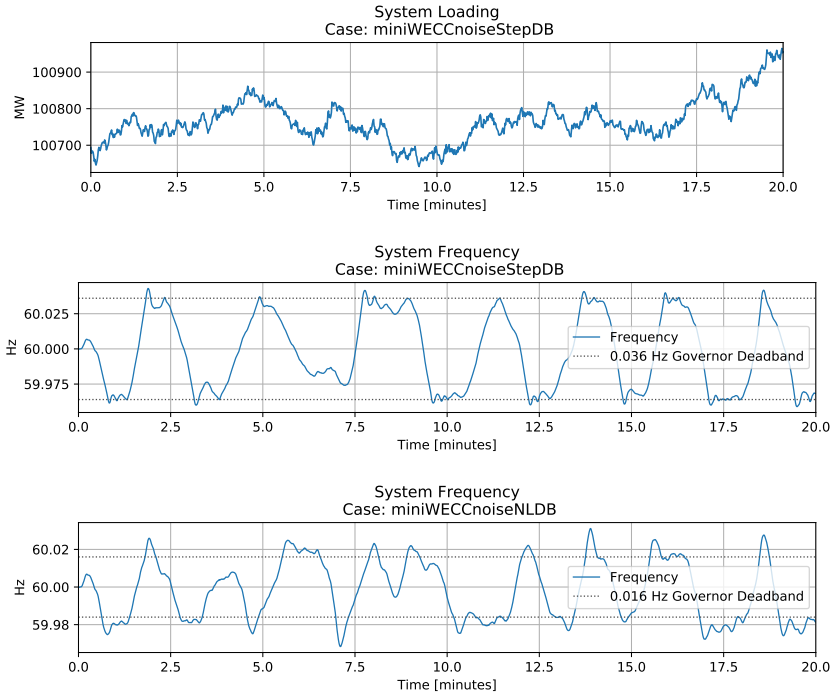


Governor Deadband



Deadband and Noise Test

20 Minutes of 0.05% Noise on all loads



Generator	Valve Travel [PU] Step DB	Valve Travel [PU] N-LD DB	Movement Reduction
17	0.87	0.24	3.63
23	0.94	0.25	3.76
76	0.86	0.23	3.74
30	0.96	0.27	3.56
32	0.94	0.26	3.62
107	0.86	0.23	3.74
41	0.20	0.06	3.33
45	0.33	0.12	2.75
53	1.00	0.27	3.70
59	0.29	0.09	3.22
Total:	7.25	2.02	3.59

Current Conclusions

- PSLTDSim output appears valid on tested systems.
- Non-linear droop deadband may reduce valve travel by 2-3 times compared to a step deadband.

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?

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