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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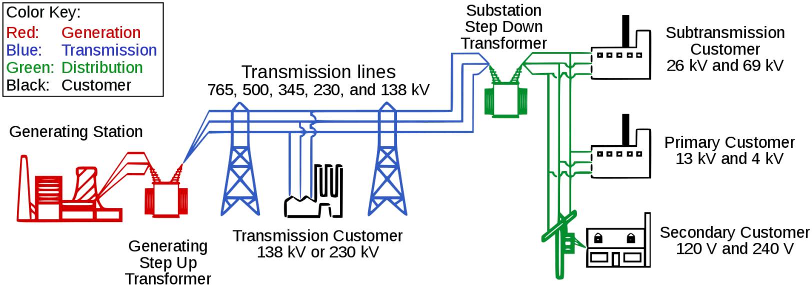
What is a Power System?



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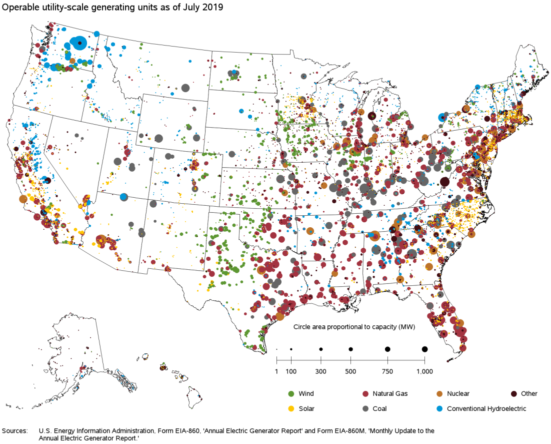
Electrical supply connected to demand.

U.S. Electric Generation



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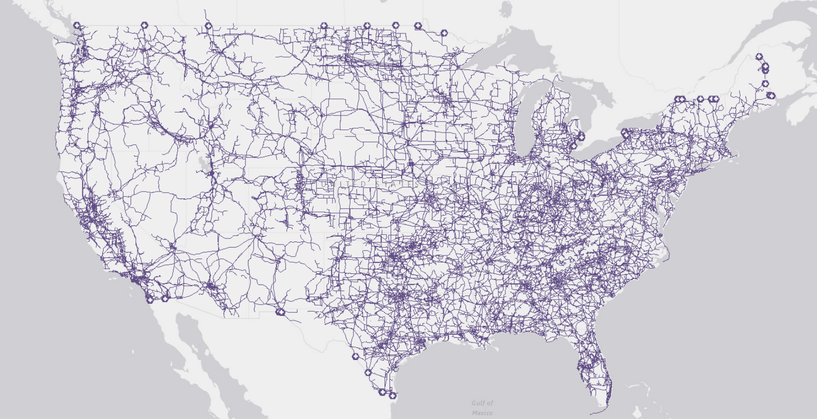
U.S. Electric Transmission Lines



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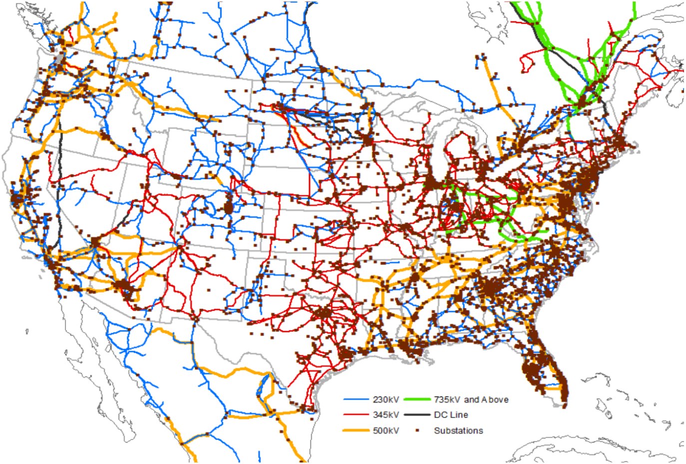
Electric Transmission Lines



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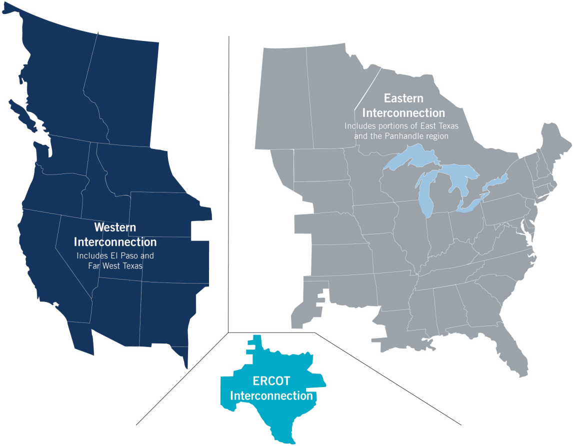
Interconnections



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Industry Software Model

WECC Model

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

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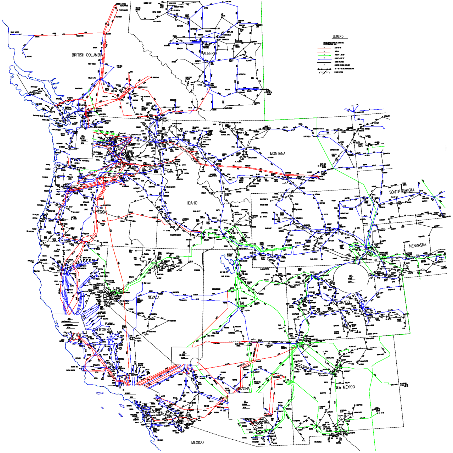
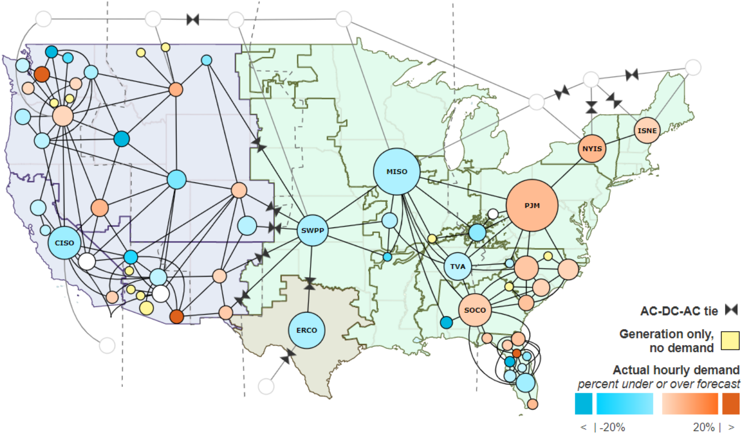


'People in Charge'

- **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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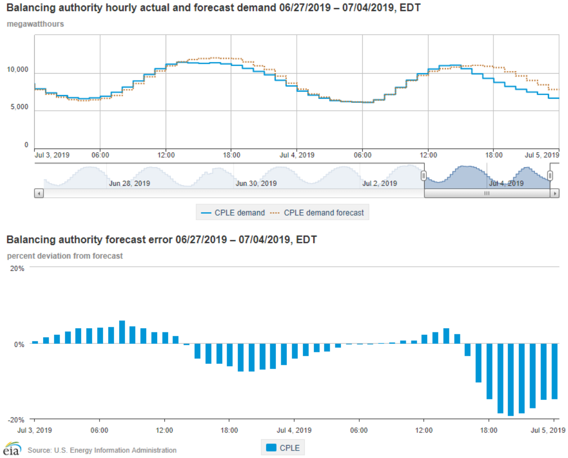
BA Action - Forcasting



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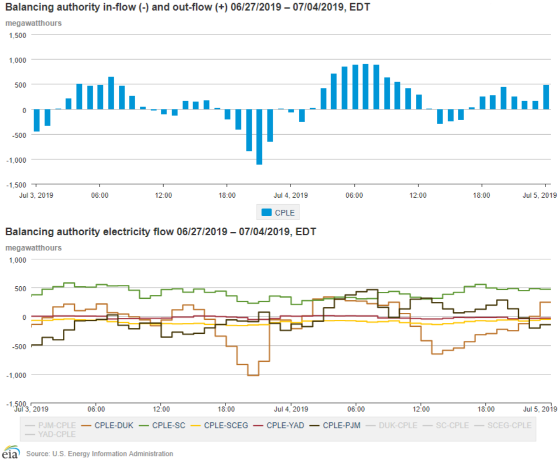
BA Action - Interchange



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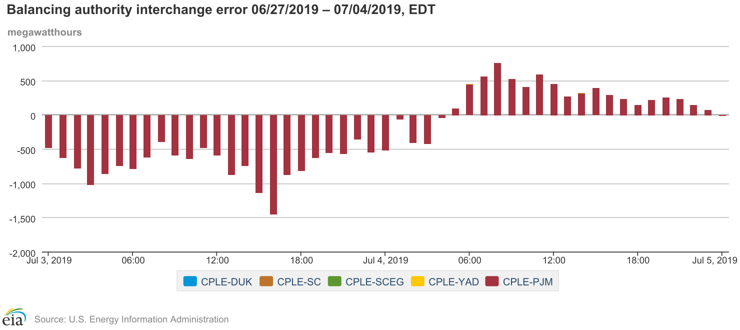
BA Action - Interchange Error

≈ Area Control Error



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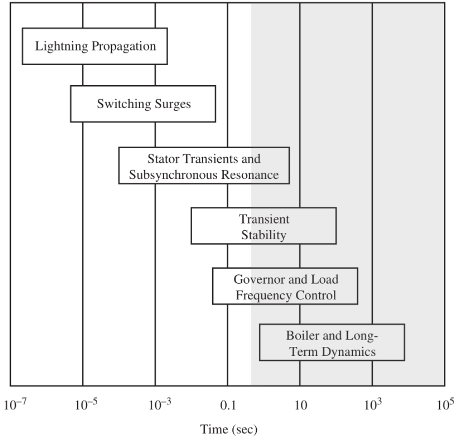
What is Long-Term?



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- 1 sec $\leftrightarrow$ hours

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

What is Dynamic Simulation?

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

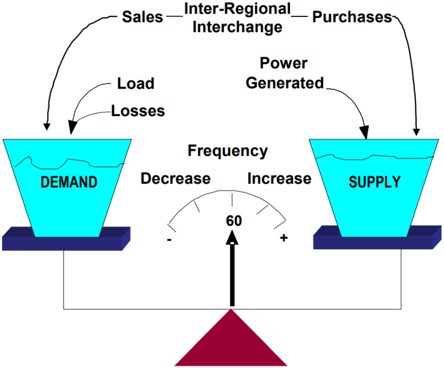
Think solving ODE's.

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

Frequency (ω)

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

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



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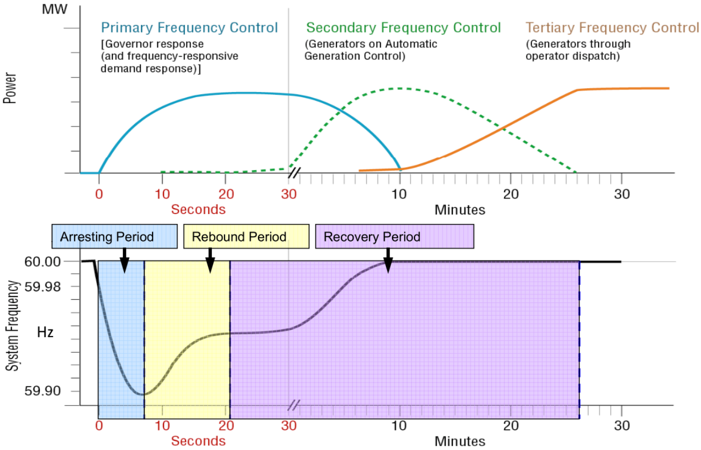
Electric load always met.

Load and losses always changing.

Automatic Controls



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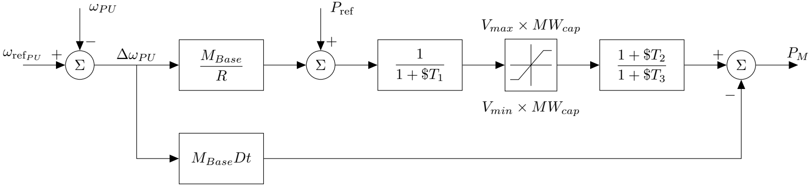
Turbine Speed Governors

Primary Control

Purpose: Adjust turbine mechanical power to arrest frequency decline.

Dynamic Variable: Fuel Valve Position

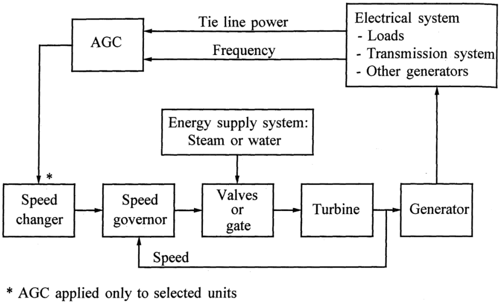


Automatic Generation Control

Secondary Control

Purpose: Eliminate Area Control Error

Dynamic Variable: Area Control Error



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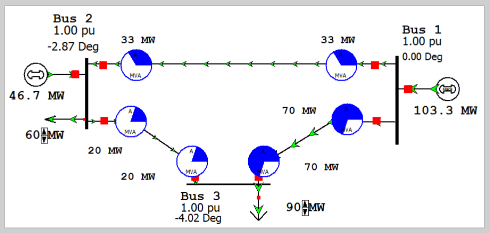
What is a Power Flow?

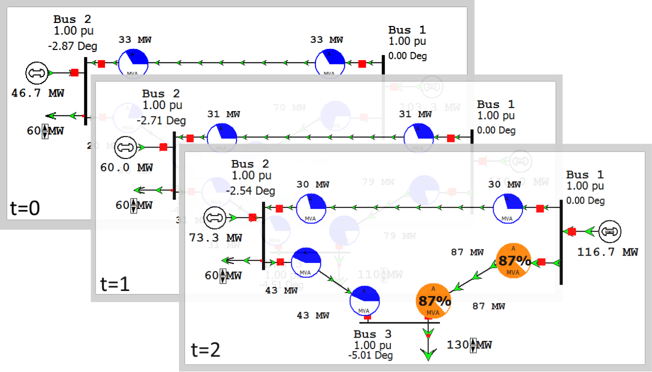
A steady state power system solution.
A *snapshot* of a stable power system.



Power flows are not dynamic.

Time-Sequenced Power Flows?

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



Why use this method?

Allows for:

- Simplifications
- Greater access to data
- Customizable models
- Modern programming language
- Further future work

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?

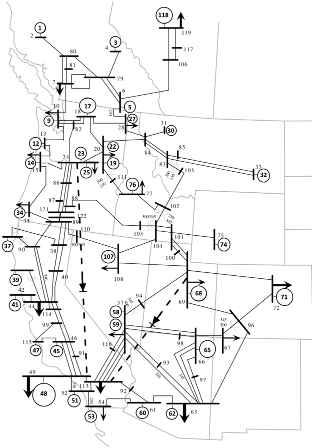
To study engineering problems involving:

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

Software Model

miniWECC

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



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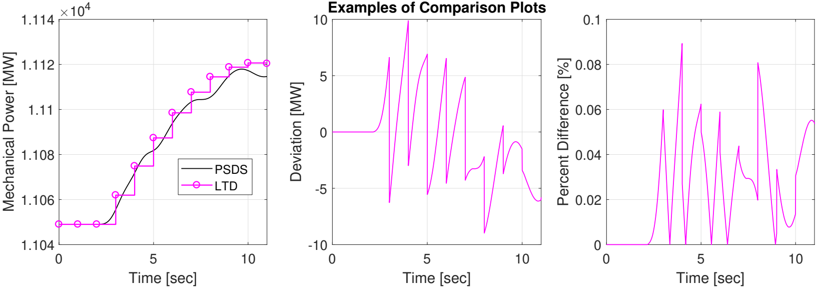
Plot Explanation

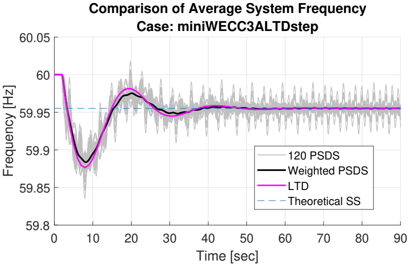


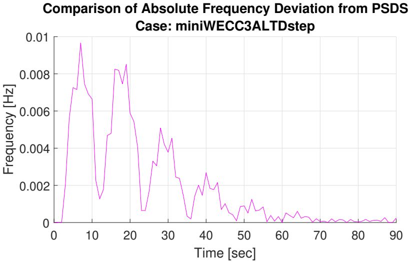
$$\text{PSDS}_{data} - \text{LTD}_{data} = \text{Deviation}_{data}$$

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

Step Perturbance Validation

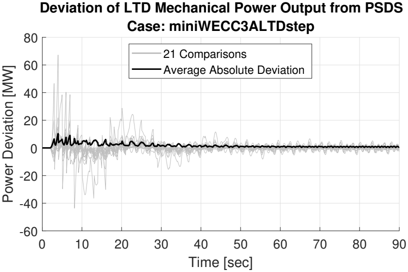
400 MW Load Step Frequency Comparison

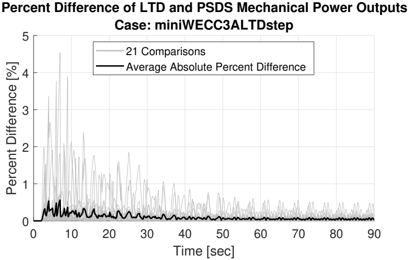




Step Perturbance Validation

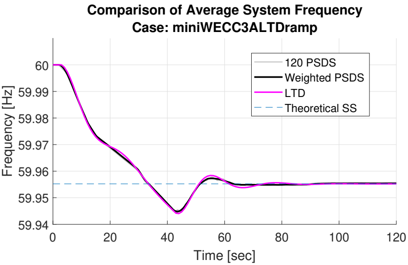
400 MW Load Step Mechanical Power Comparison

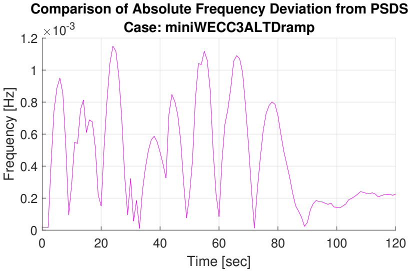




Ramp Perturbance Validation

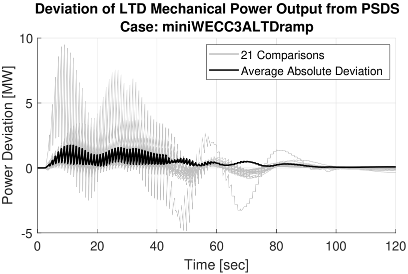
20 second 400 MW Load Ramp Frequency Comparison

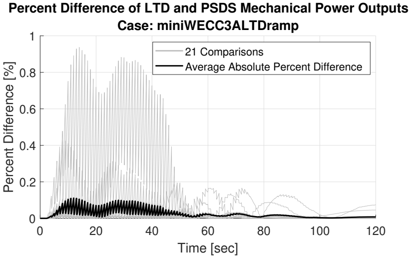




Ramp Perturbance Validation

20 second 400 MW Load ramp Mechanical Power Comparison

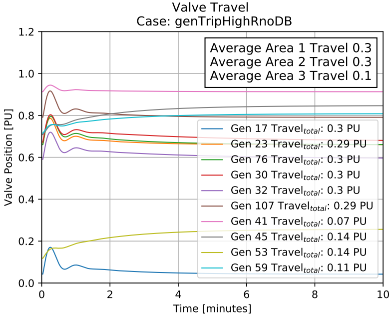




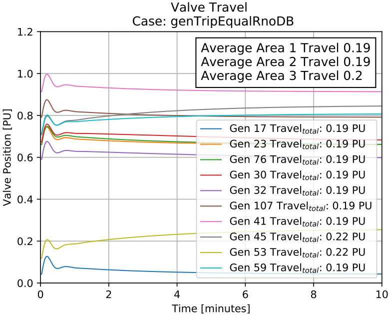
Area Droop and Valve Travel

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

Area 3 droop = 0.2



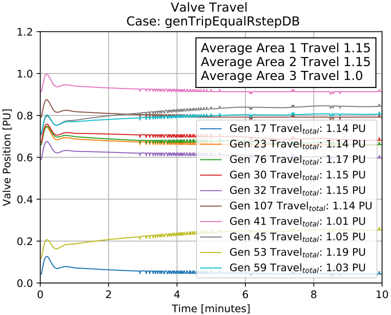
Area 3 droop = 0.05



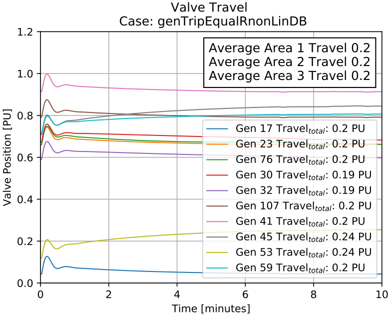
Deadband and Valve Travel

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

Step Deadband



Non-Linear Droop Deadband



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?

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