



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

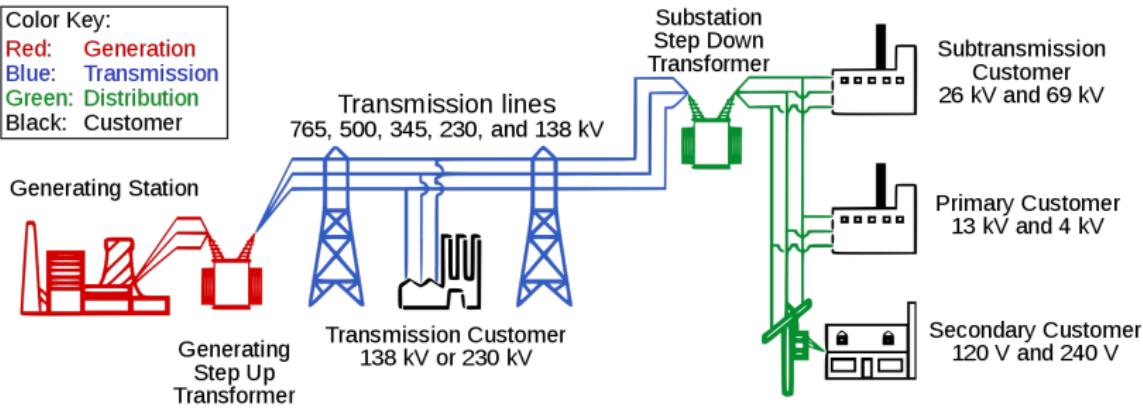
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Montana Technological University - Master's Thesis Research Project

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What is a Power System?

Color Key:
Red: Generation
Blue: Transmission
Green: Distribution
Black: Customer

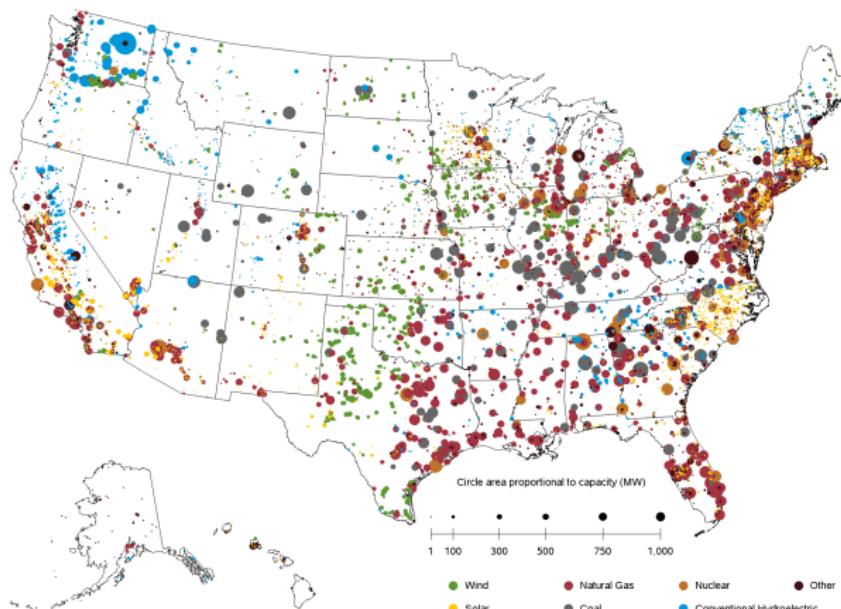


Electrical supply connected to demand.

Physical Structure

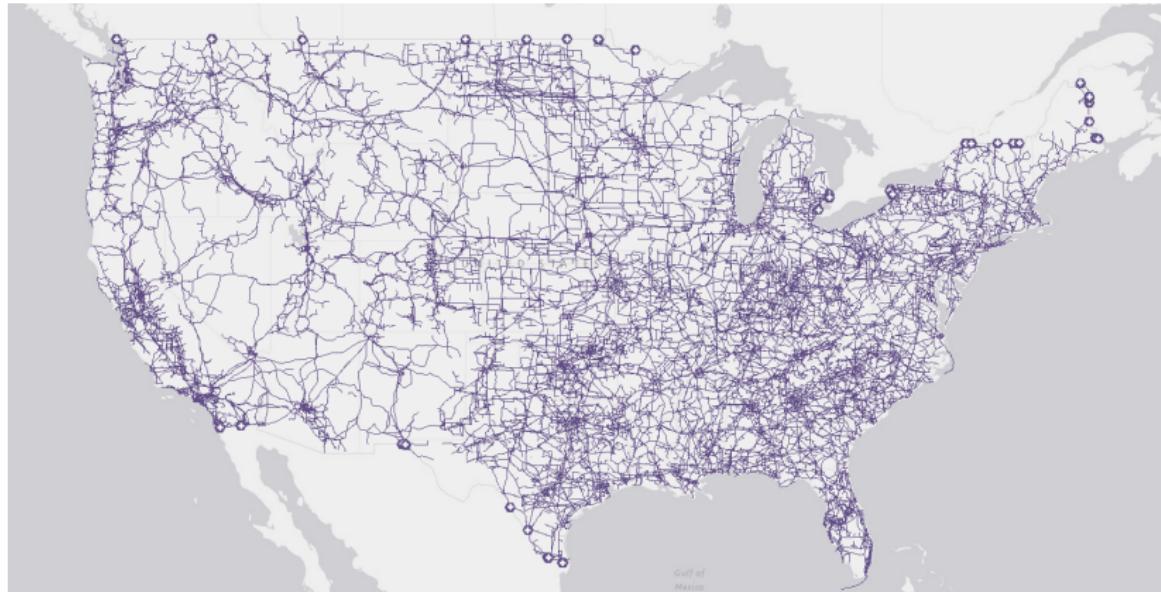
U.S. Electric Generation

Operable utility-scale generating units as of July 2019

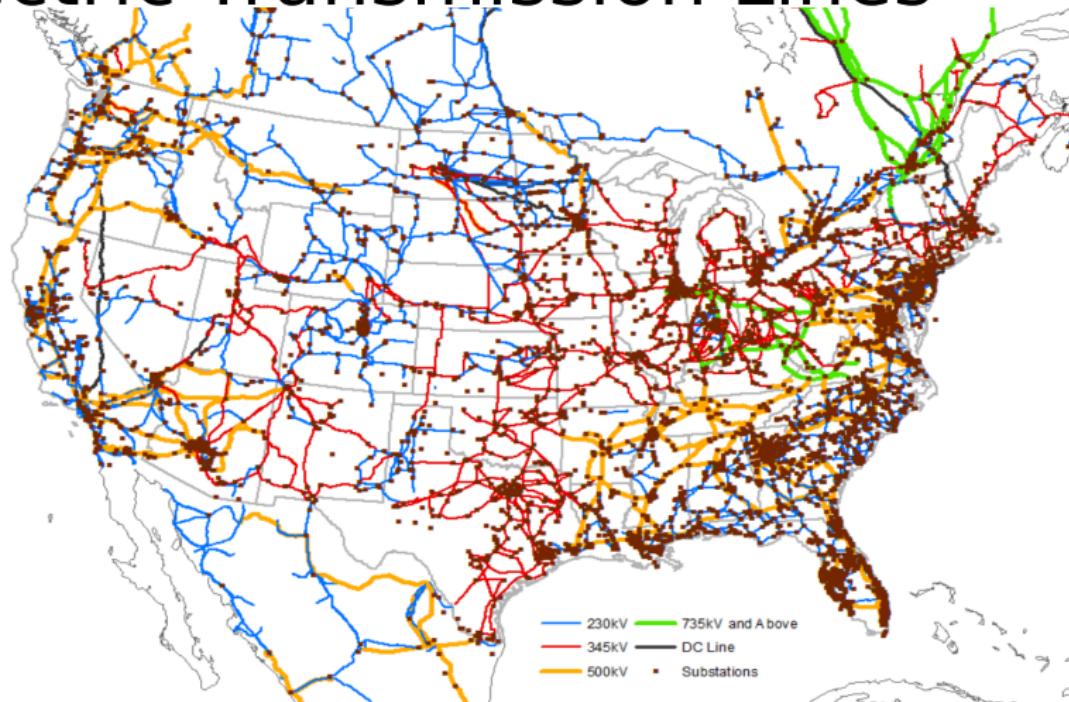


Physical Structure

U.S. Electric Transmission Lines



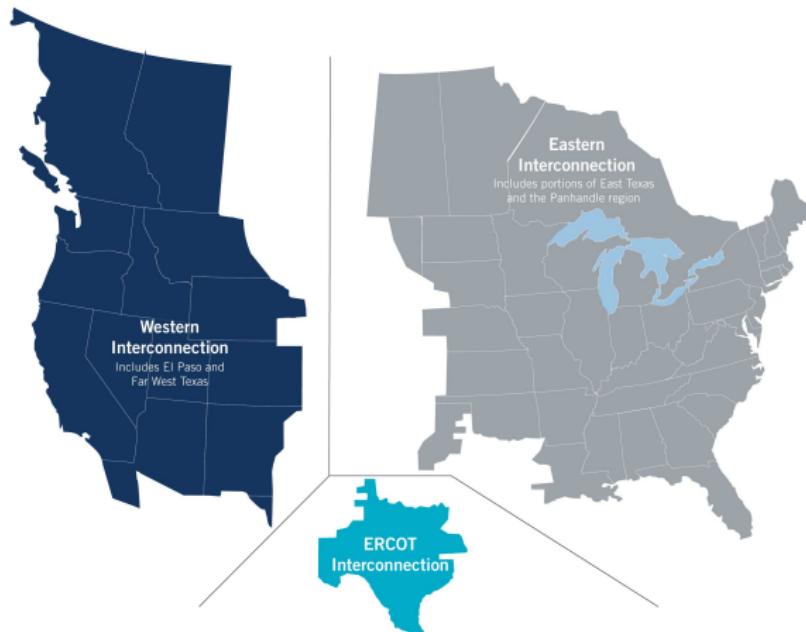
Electric Transmission Lines





Physical Structure

Interconnections

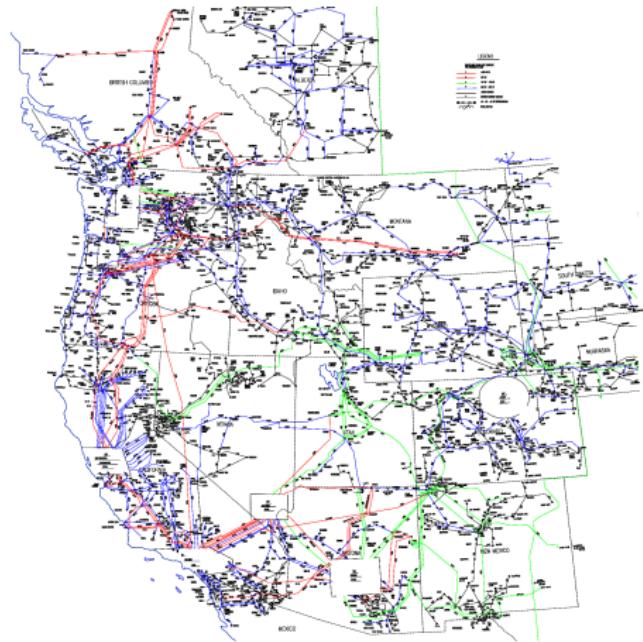


Physical Structure

Industry Software Model

WECC Model

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



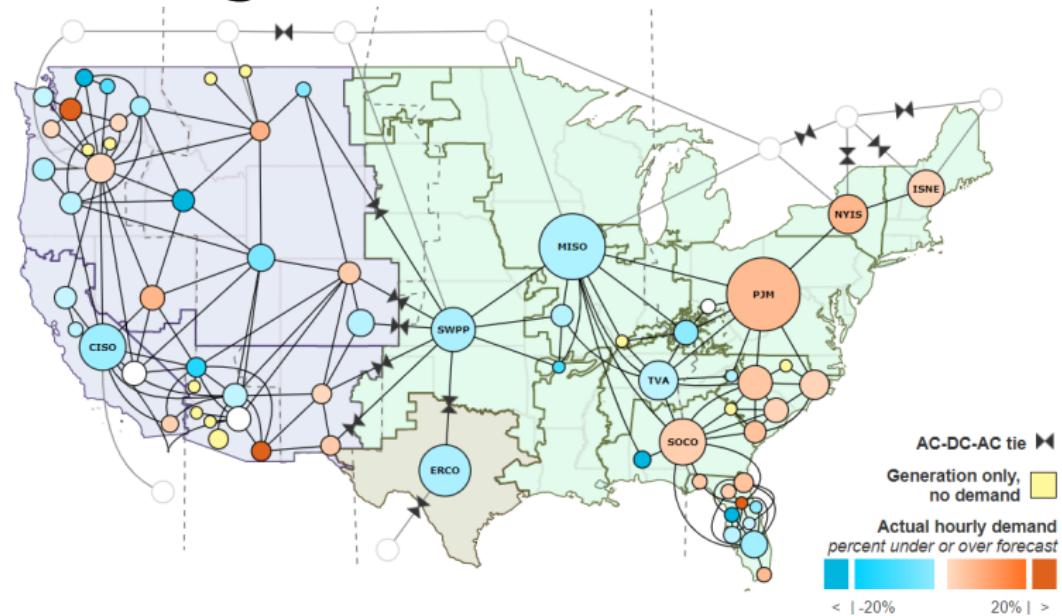


'People in Charge'

- ▶ **FERC** Federal Energy Regulatory Commission
Part of the Department of Energy
- ▶ **NERC** North American Electric Reliability Corp.
Authority 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.

Operational Structure

Balancing Authorities (BAs)





Operational Structure

BA Action - Forecasting

Balancing authority hourly actual and forecast demand 06/27/2019 – 07/04/2019, EDT

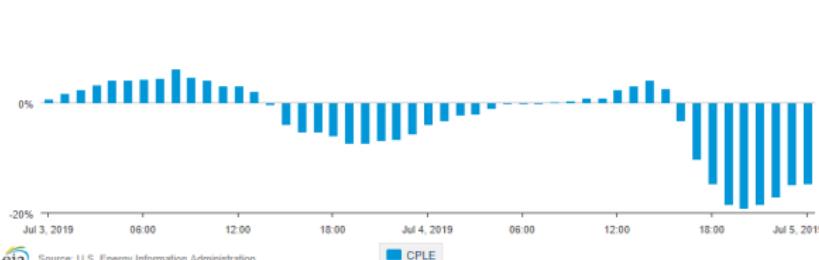
megawatthours



Balancing authority forecast error 06/27/2019 – 07/04/2019, EDT

percent deviation from forecast

20%

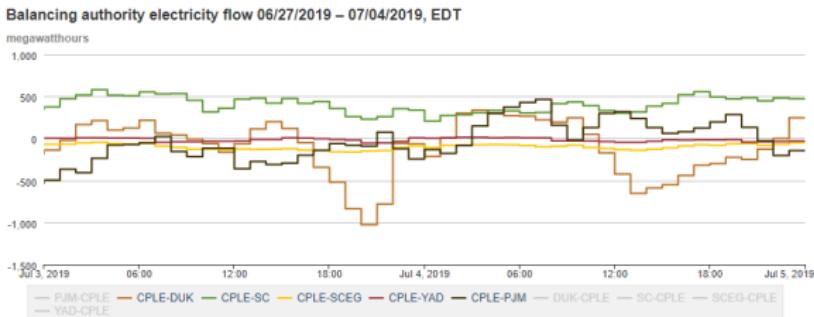
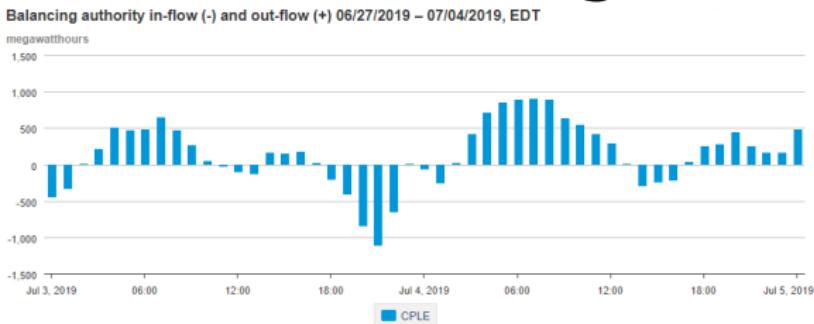


Source: U.S. Energy Information Administration



Operational Structure

BA Action - Interchange



BA Action - Interchange Error

≈ Area Control Error

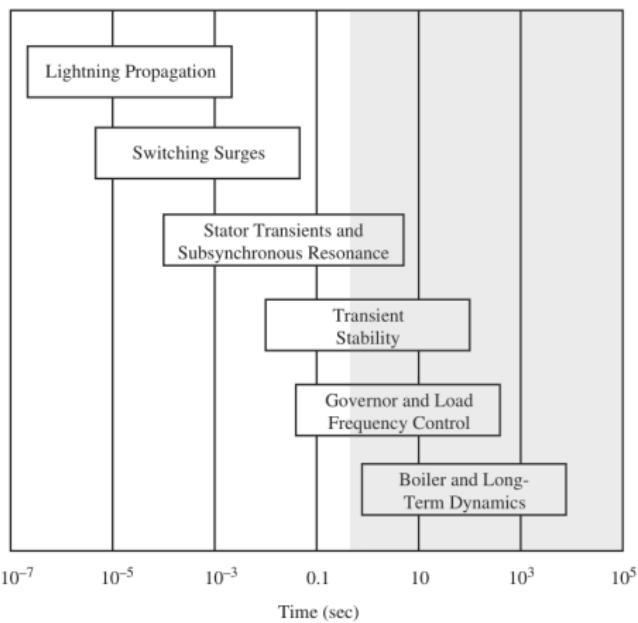
Balancing authority interchange error 06/27/2019 – 07/04/2019, EDT



Source: U.S. Energy Information Administration

Explanation of Wording

What is Long-Term?



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

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Explanation of Wording

What is Dynamic Simulation?

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

Think solving ODE's.

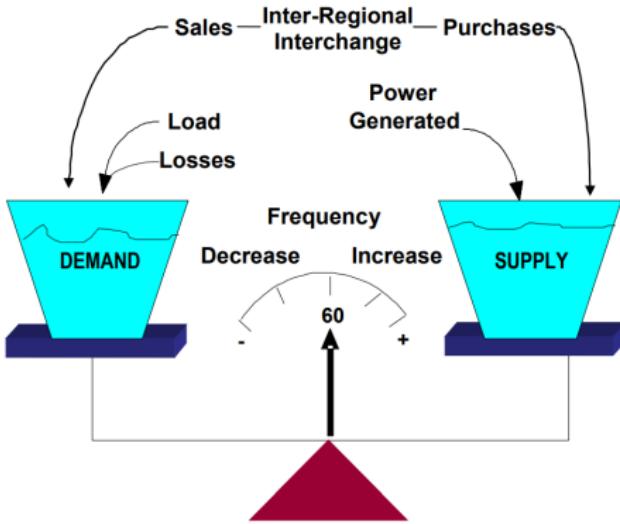
How certain qualities of a power system may change over time in response to a known perturbation.

Dynamic Concepts of Interest

Frequency (ω)

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

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

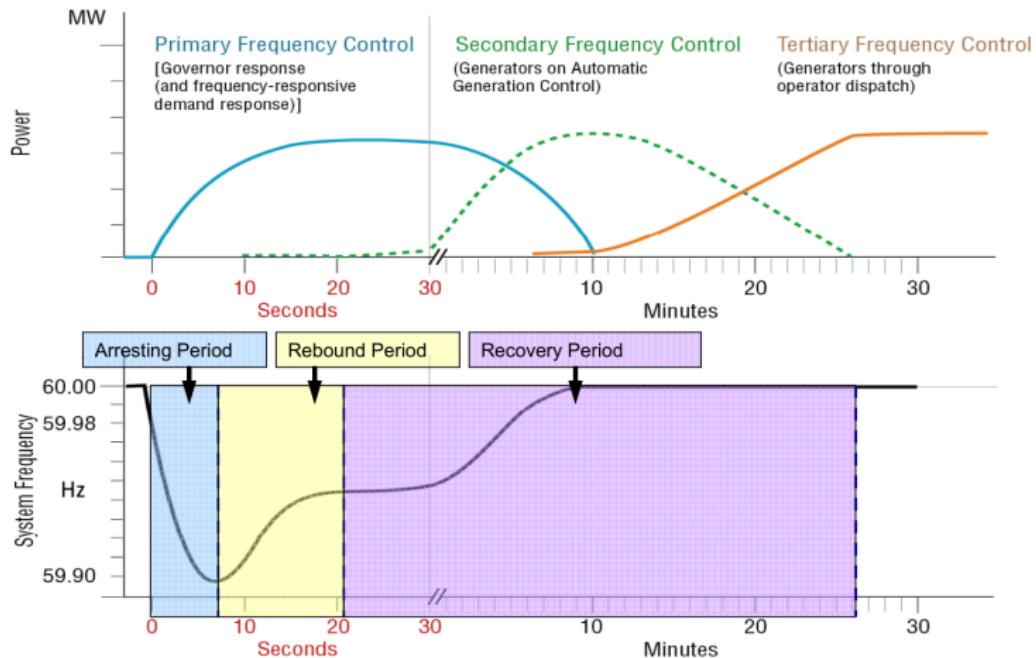


Electric load always met.

Load and losses always changing.

Dynamic Concepts of Interest

Automatic Controls

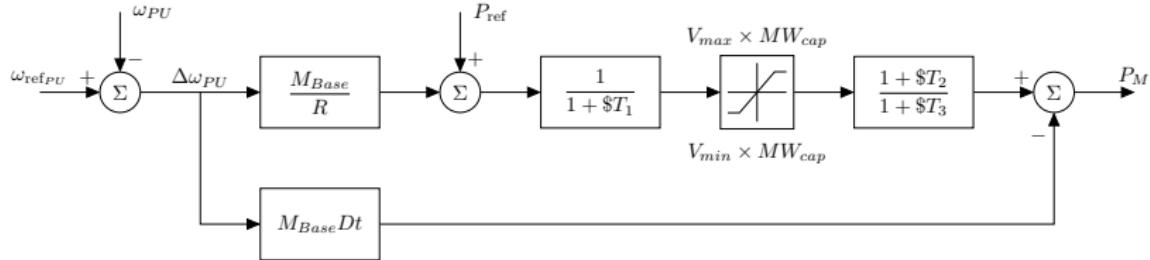


Turbine Speed Governors

Primary Control

Purpose: Adjust turbine mechanical power to arrest frequency decline.

Dynamic Variable: Fuel Valve Position



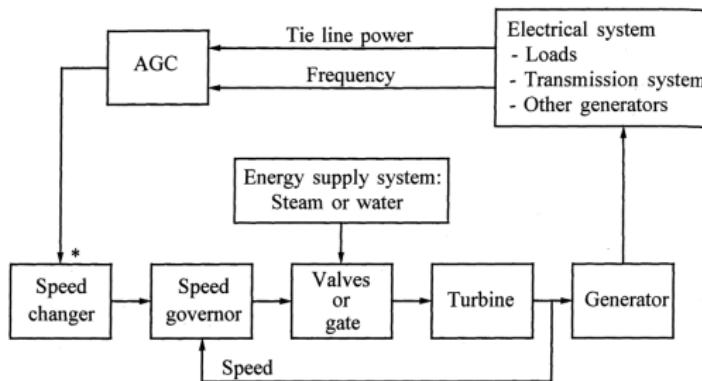
Dynamic Concepts of Interest

Automatic Generation Control

Secondary Control

Purpose: Eliminate Area Control Error

Dynamic Variable: Area Control Error

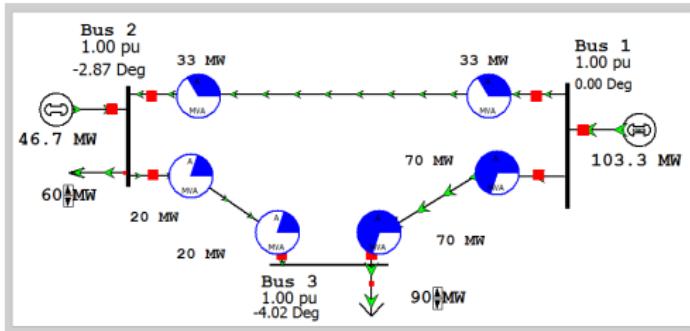


* AGC applied only to selected units

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What is a Power Flow?

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

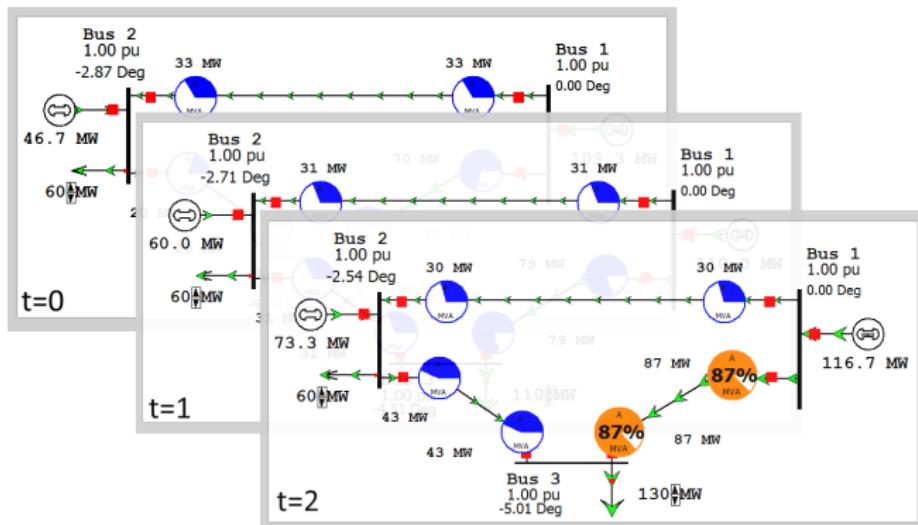


Power flows are not dynamic.

Explanation of Computational Approach

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:

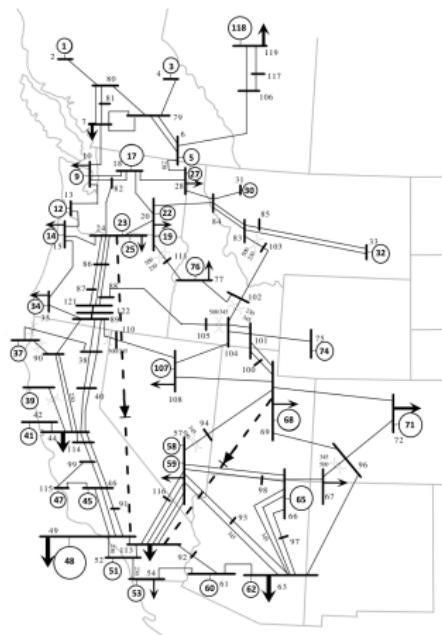
- ▶ Long-term events (i.e. Wind Ramps)
- ▶ Multi-Area Power Interactions
 - ▶ Governor and AGC interaction
 - ▶ Governor and AGC settings
- ▶ Ways to reduce machine effort while meeting reliability standards.

Quick Validation

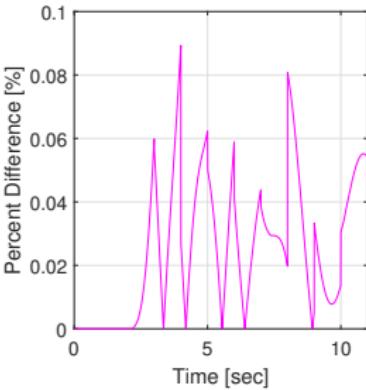
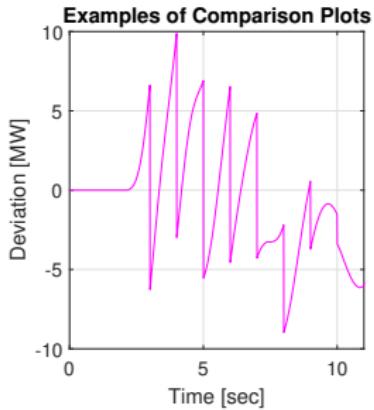
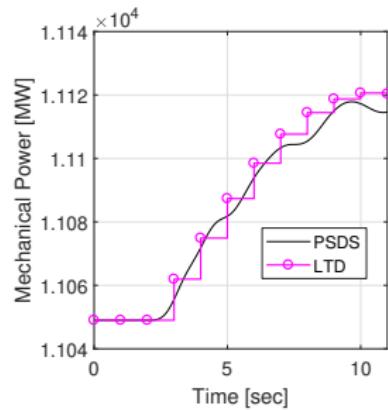
Software Model

miniWECC

- ▶ 34 Generators
- ▶ 104 Lines
- ▶ 23 Loads
- ▶ 120 Buses



Plot Explanation

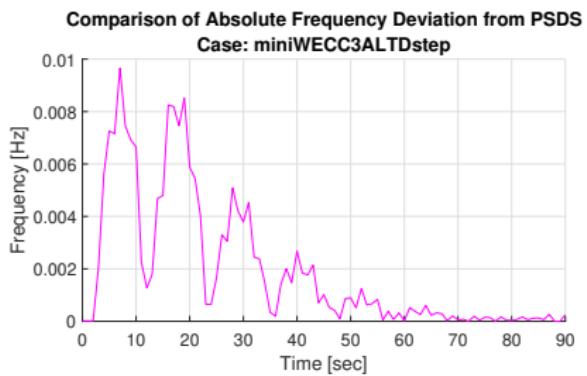
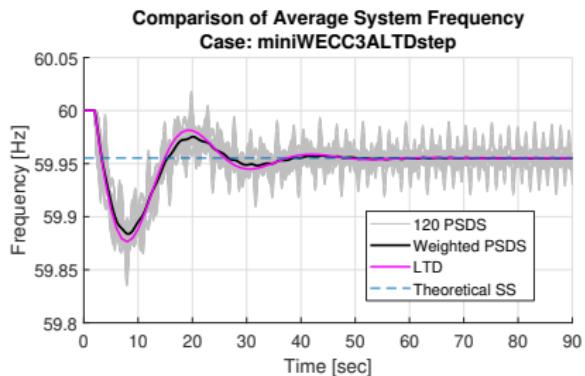


$$\text{PSDS}_{data} - \text{LTD}_{data} = \text{Deviation}_{data}$$

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

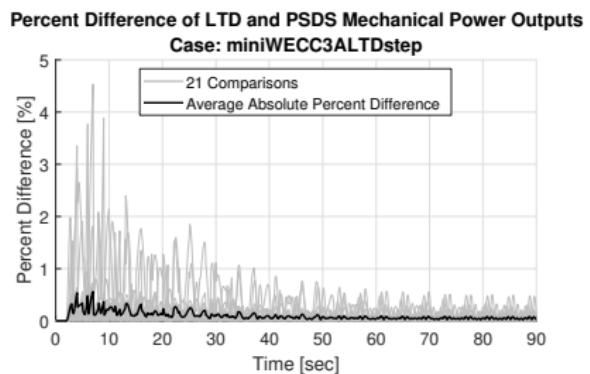
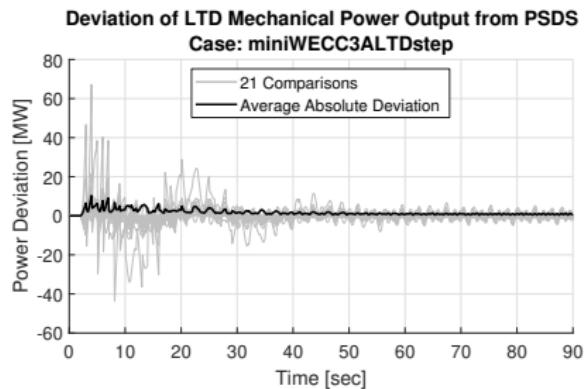
Step Perturbation Validation

400 MW Load Step Frequency Comparison



Step Perturbation Validation

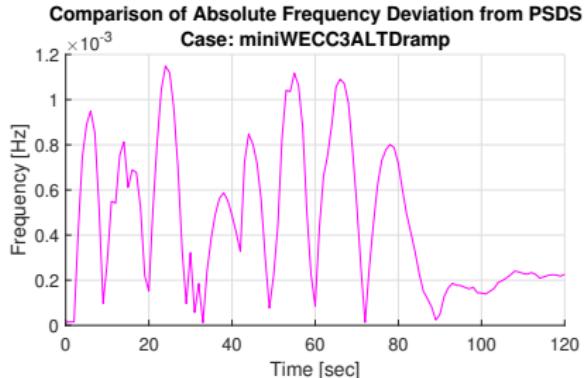
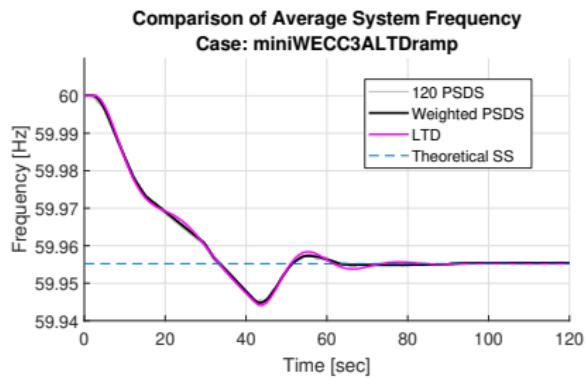
400 MW Load Step Mechanical Power Comparison



Quick Validation

Ramp Perturbation Validation

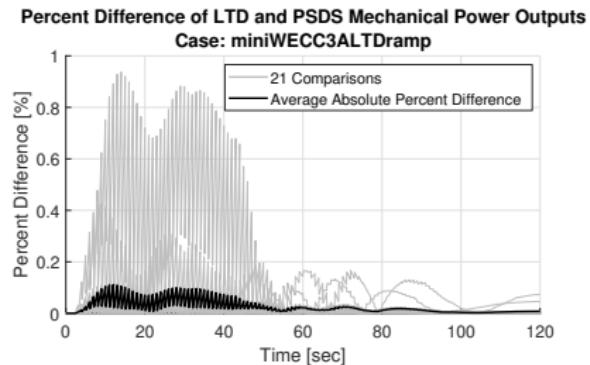
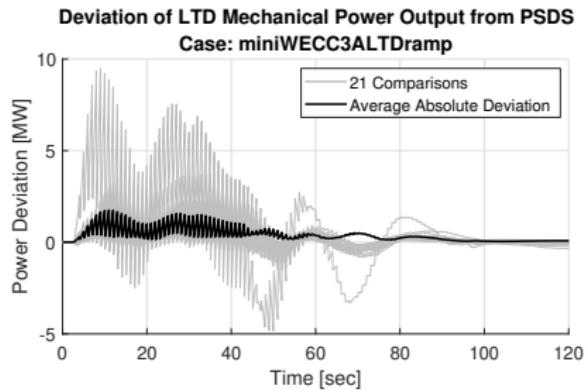
20 second 400 MW Load Ramp Frequency Comparison



Quick Validation

Ramp Perturbation Validation

20 second 400 MW Load ramp Mechanical Power Comparison



Area Droop and Valve Travel

Compare Step from Area with low and high droop, how other areas react. side by side graph table with percent diff

Current Conclusions

- ▶ Software (PSLTDSim) output appears valid for tested 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?

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