



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

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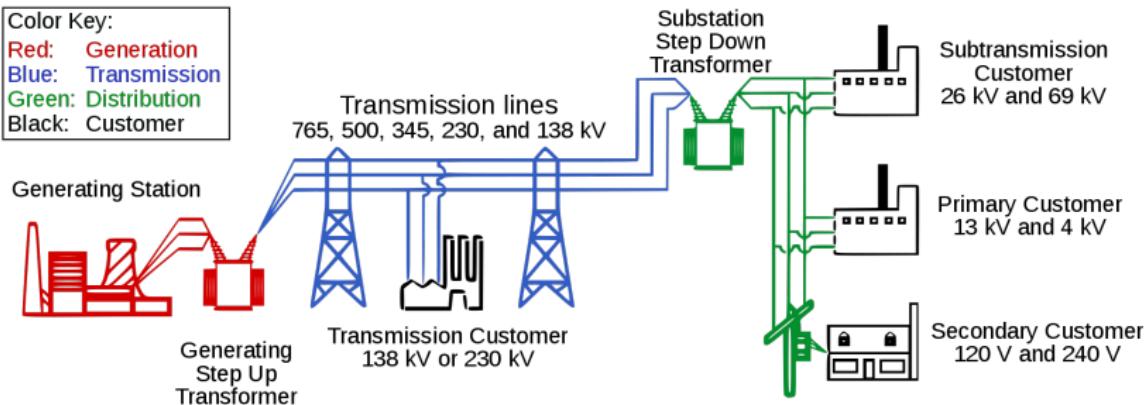
Montana Technological University - Master's Thesis Research Project

October 22nd, 2019

Physical Structure

What is a Power System?

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



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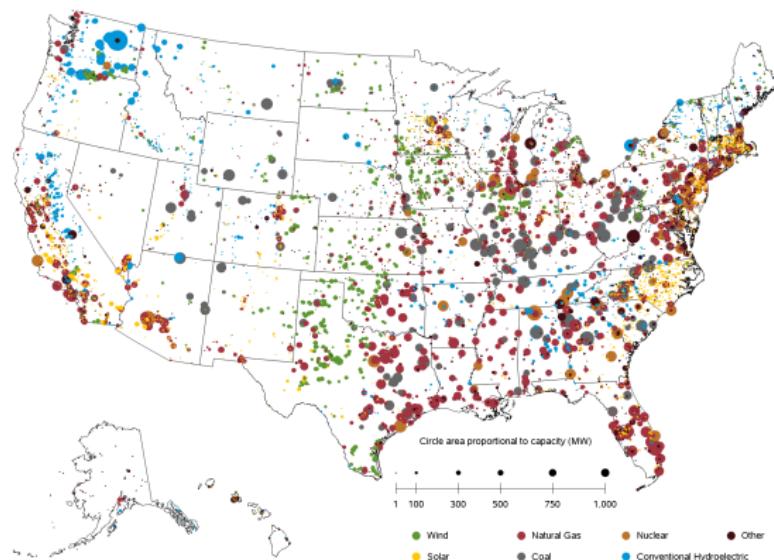
Electrical supply connected to demand.



Physical Structure

U.S. Electric Generation

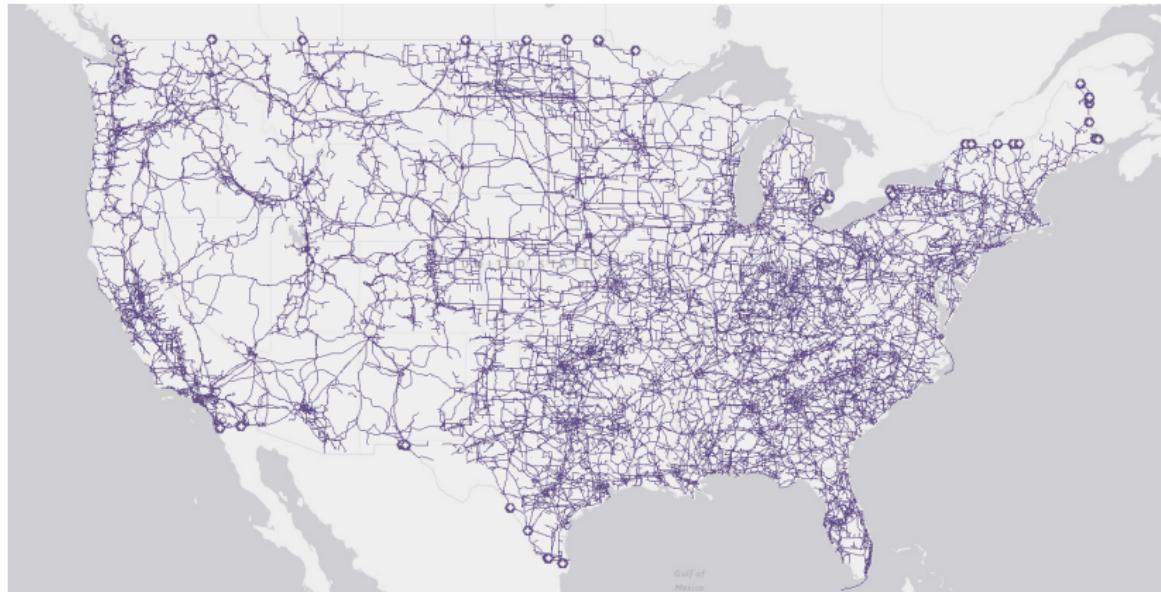
Operable utility-scale generating units as of July 2019



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."

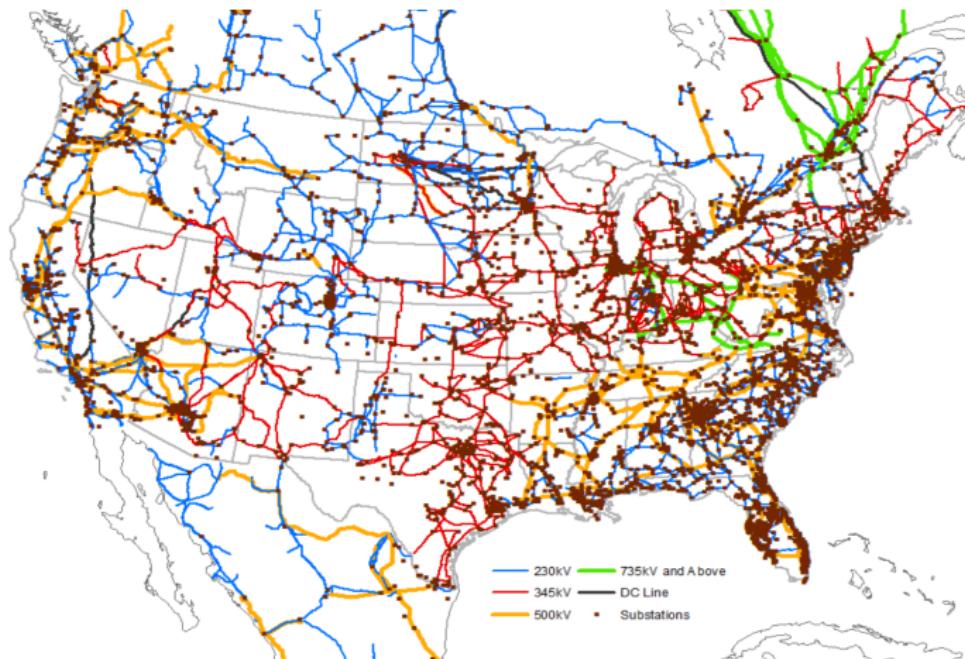
[16]

U.S. Electric Transmission Lines

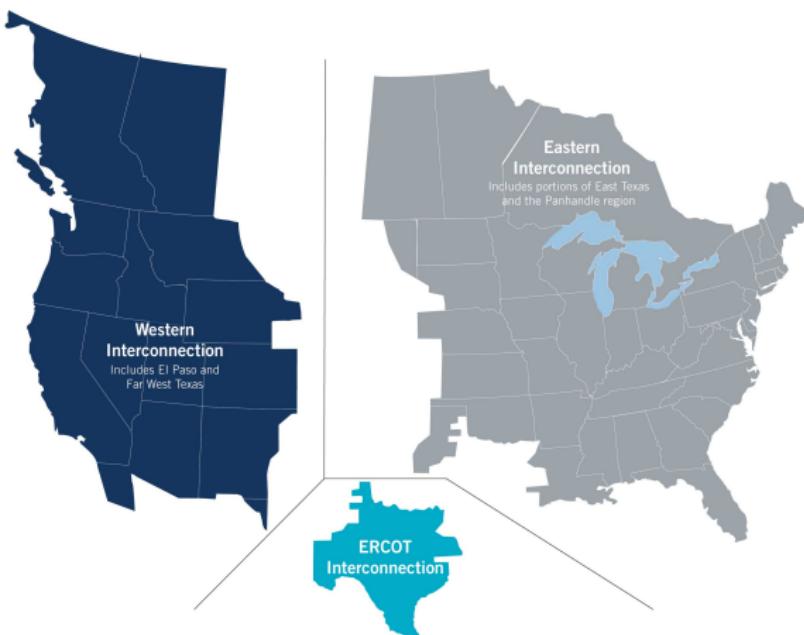


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Electric Transmission Lines



Interconnections



[6]

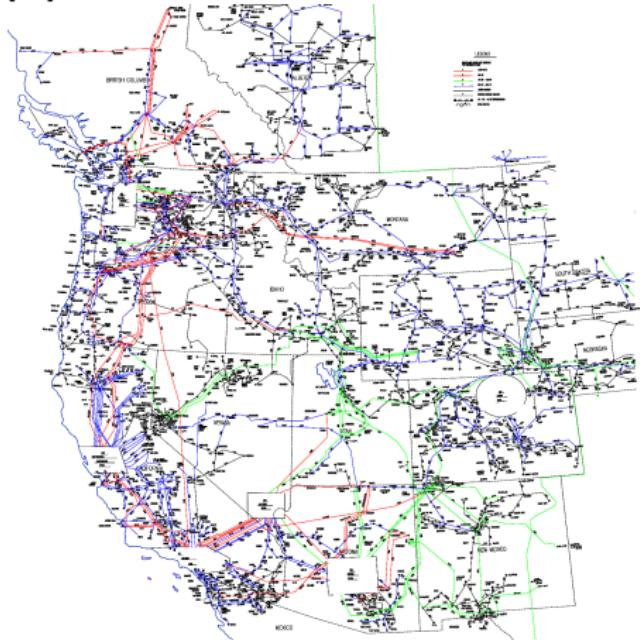
Physical Structure

Industry Software Model

WECC Model

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

[20]



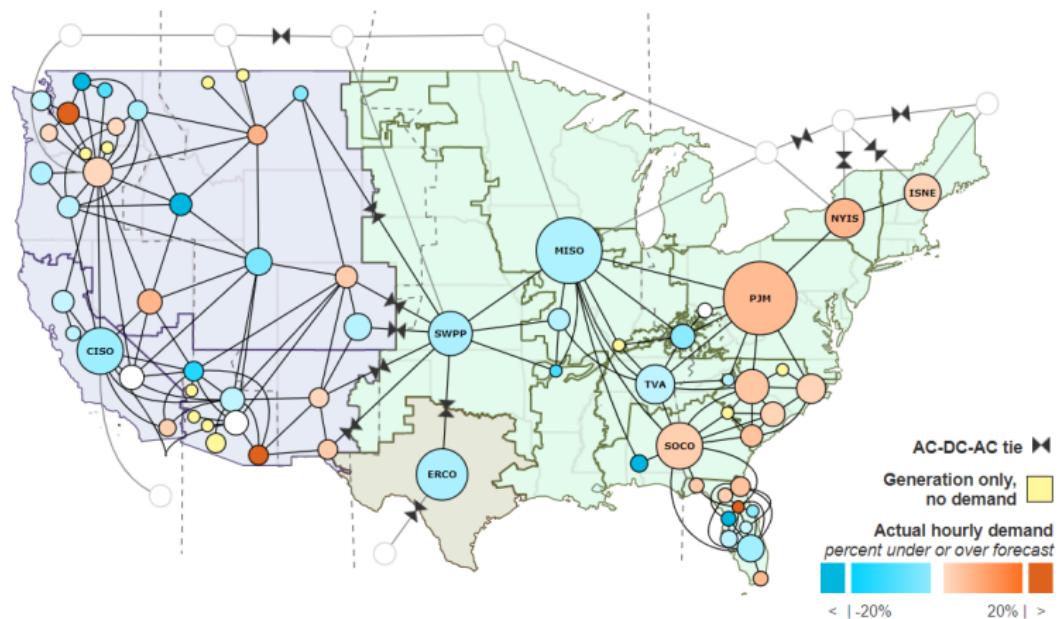


'People in Charge'

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



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Operational Structure

BA Action - Forecasting

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

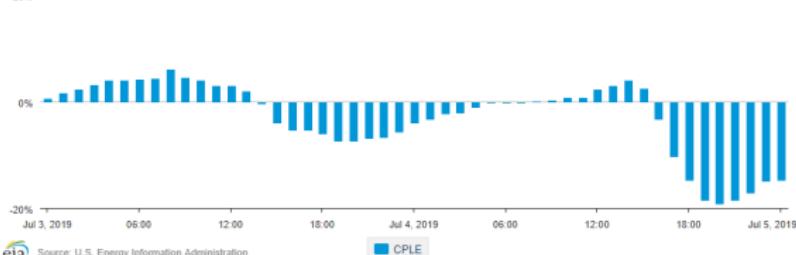
megawatthours



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

percent deviation from forecast

20%



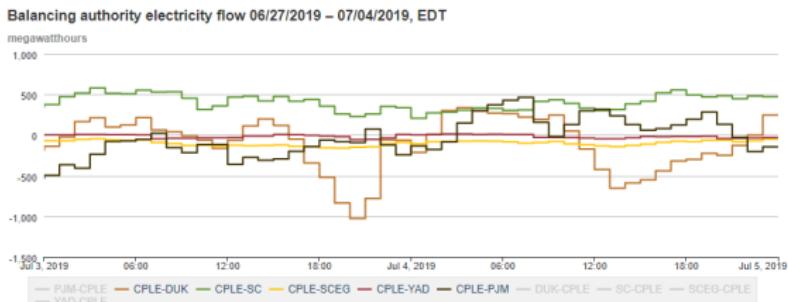
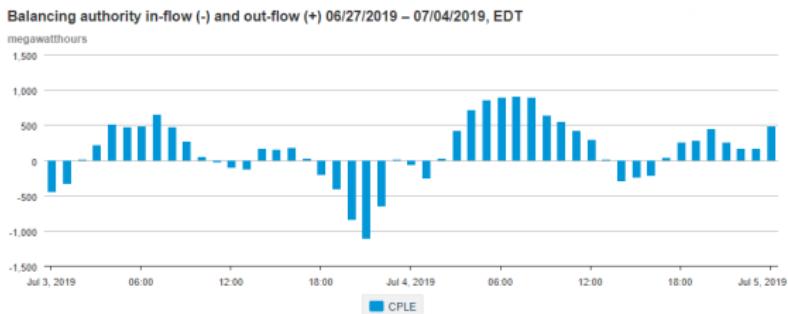
Source: U.S. Energy Information Administration

[27]



Operational Structure

BA Action - Interchange



Source: U.S. Energy Information Administration

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BA Action - Interchange Error

≈ Area Control Error

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

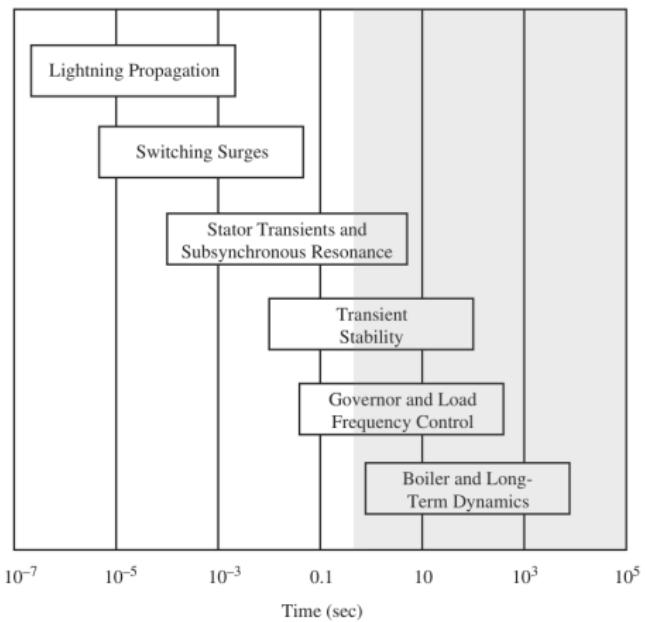


Source: U.S. Energy Information Administration

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Explanation of Wording

What is Long-Term?



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- 1 sec \leftrightarrow hours
- ⋮
- 10→60 minute simulations
- 1 sec time step



Explanation of Wording

What is Dynamic Simulation?

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

Think solving ODE's.

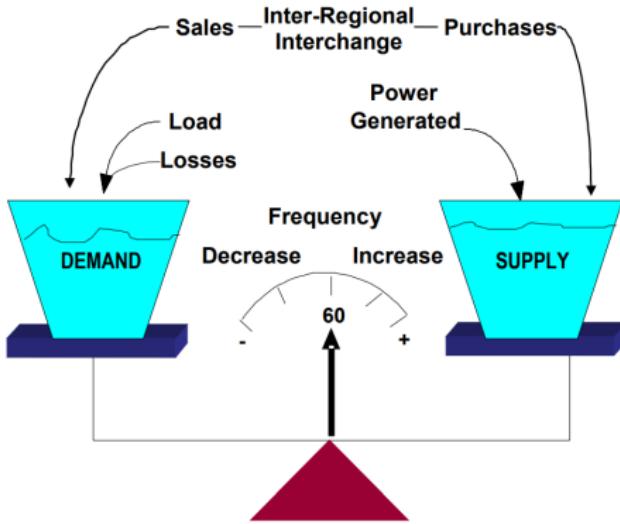
How certain qualities of a power system may change over time in response to a known perturbation.

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.

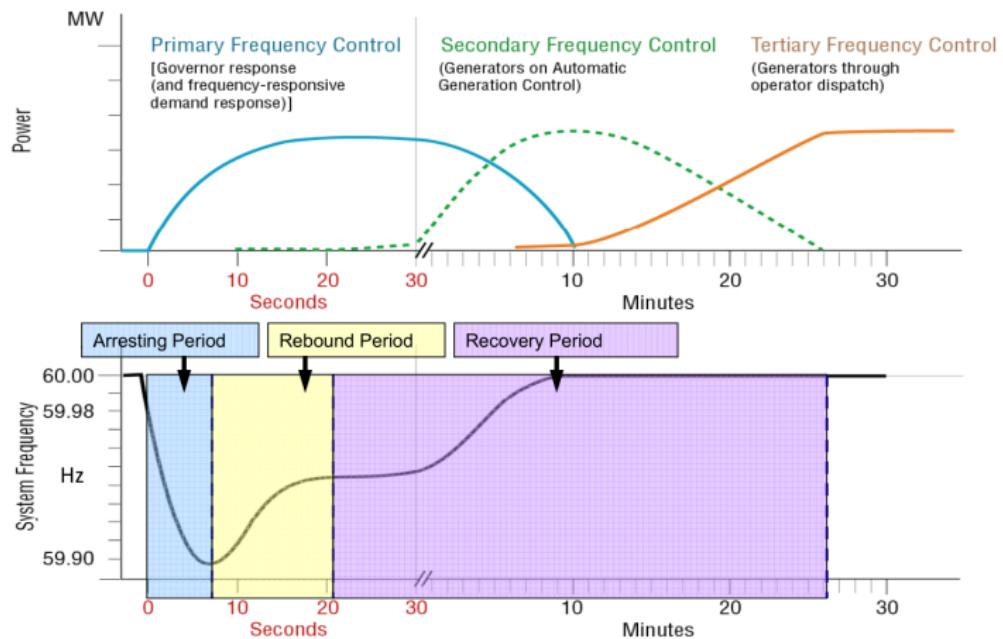
[25]

Load and losses always changing.



Dynamic Concepts of Interest

Automatic Controls

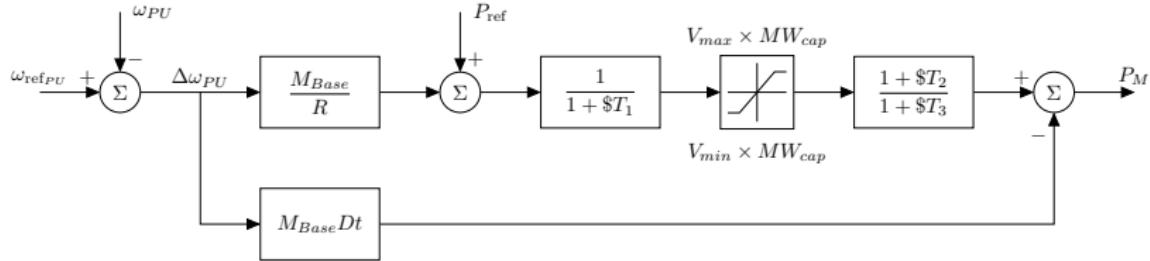


Turbine Speed Governors

Primary Control

Purpose: Adjust turbine mechanical power to arrest frequency decline.

Dynamic Variable: Fuel Valve Position



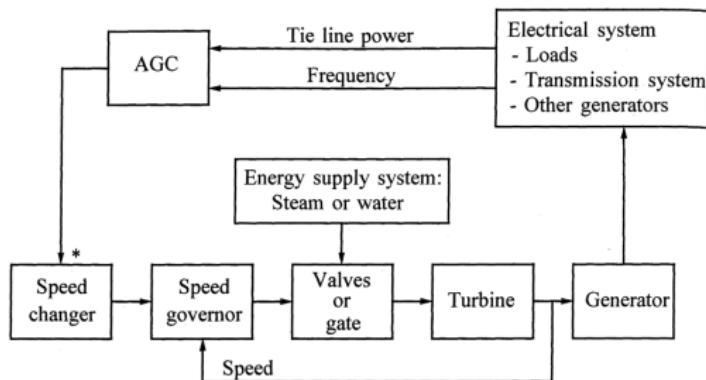
Dynamic Concepts of Interest

Automatic Generation Control

Secondary Control

Purpose: Eliminate Area Control Error

Dynamic Variable: Area Control Error

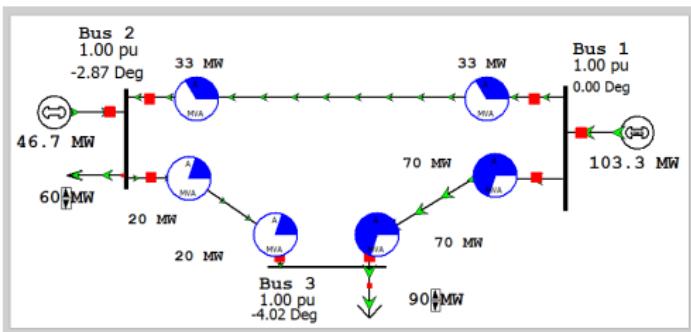


* AGC applied only to selected units

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What is a Power Flow?

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

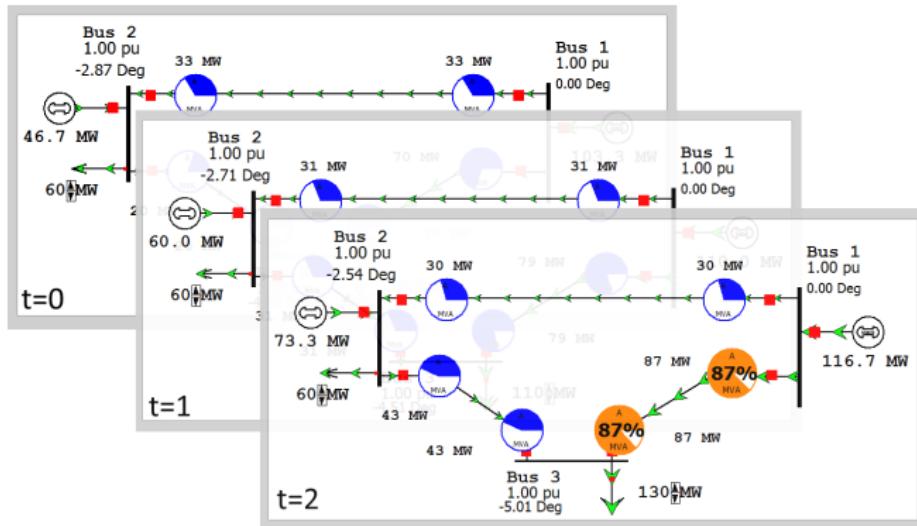


Power flows are not dynamic.

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:

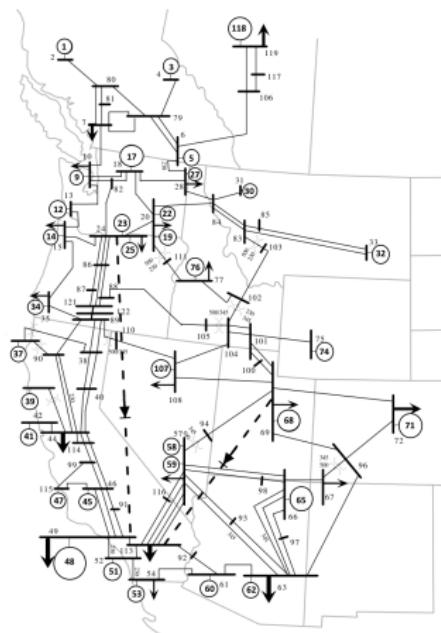
- ▶ Long-term events (i.e. Wind Ramps)
- ▶ Multi-Area Power Interactions
 - ▶ Governor and AGC interaction
 - ▶ Governor and AGC settings
- ▶ Ways to reduce machine effort while meeting reliability standards.

Quick Validation

Software Model

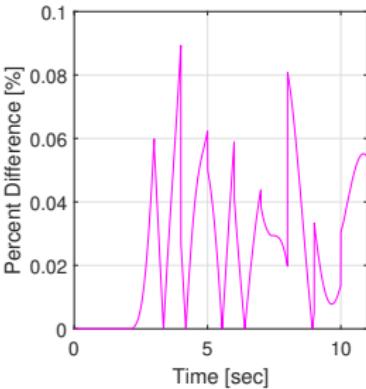
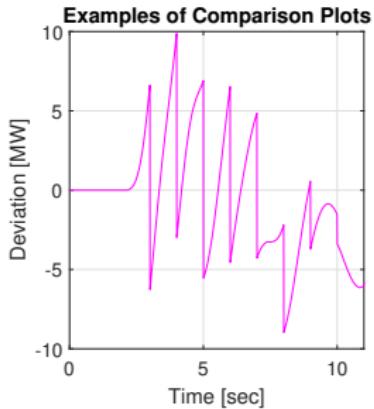
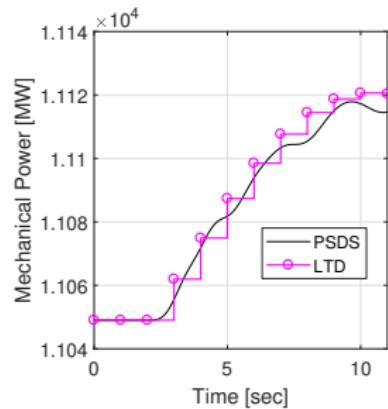
miniWECC

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



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Plot Explanation



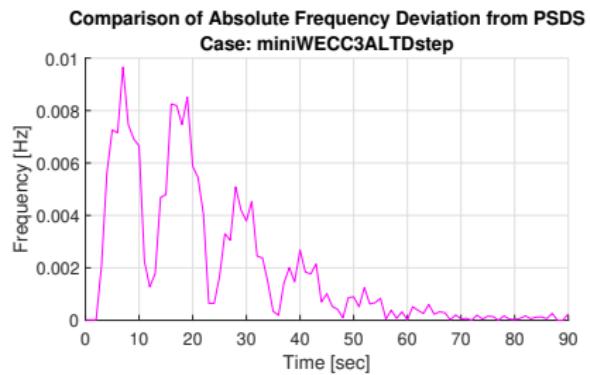
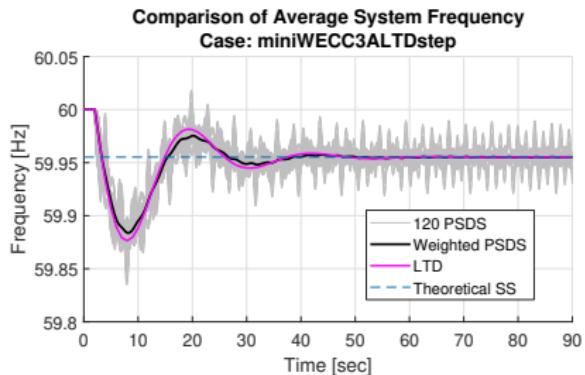
$$\text{PSDS}_{data} - \text{LTD}_{data} = \text{Deviation}_{data}$$

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

Quick Validation

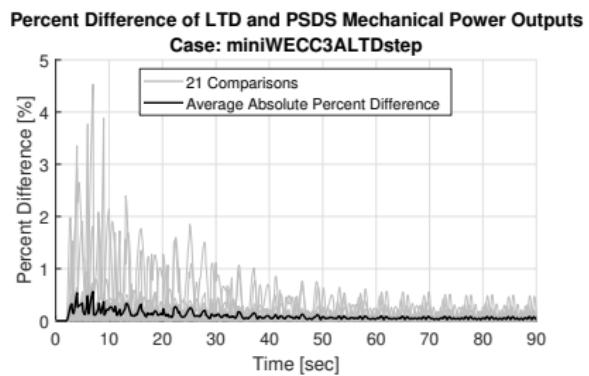
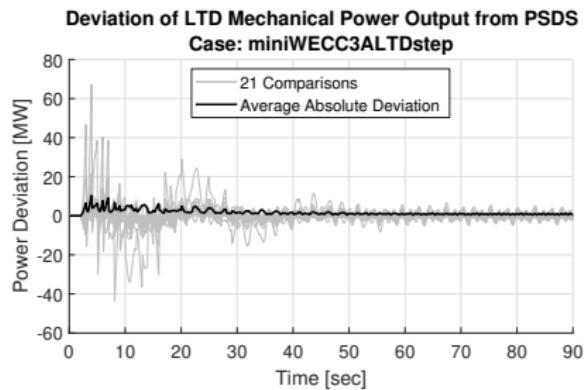
Step Perturbation Validation

400 MW Load Step Frequency Comparison



Step Perturbation Validation

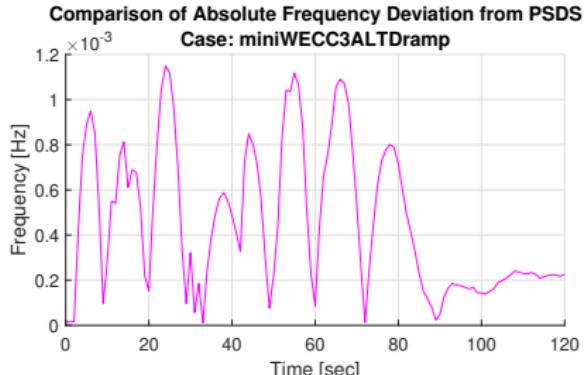
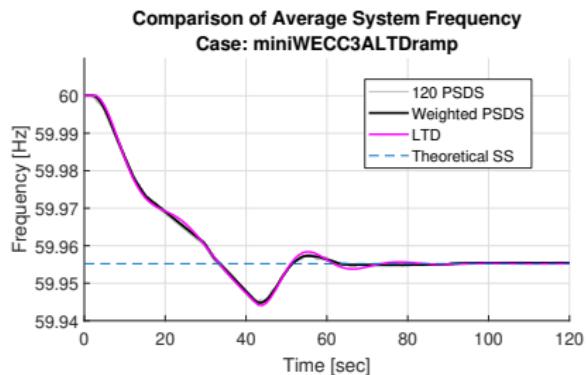
400 MW Load Step Mechanical Power Comparison



Quick Validation

Ramp Perturbation Validation

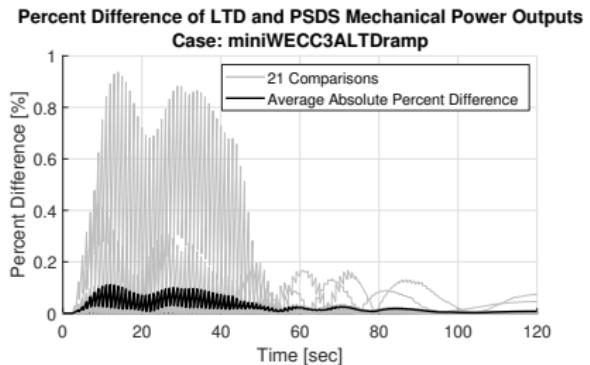
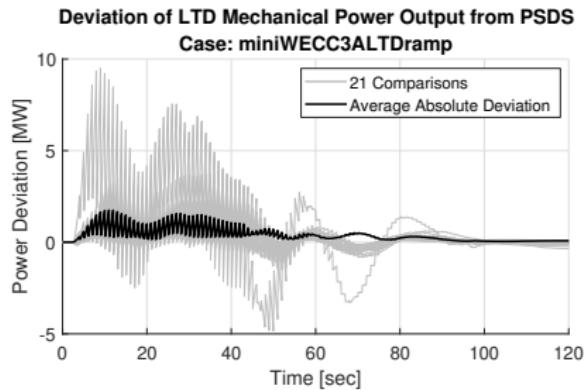
20 second 400 MW Load Ramp Frequency Comparison



Quick Validation

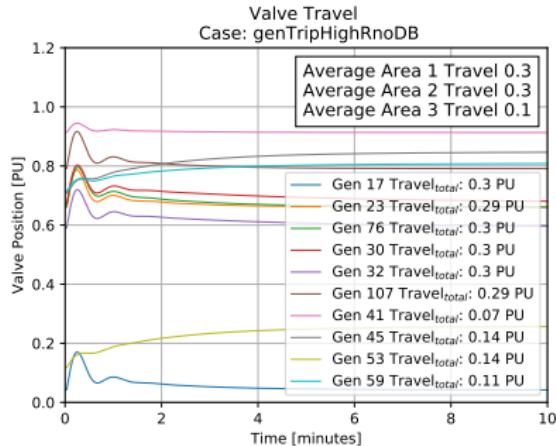
Ramp Perturbation Validation

20 second 400 MW Load ramp Mechanical Power Comparison

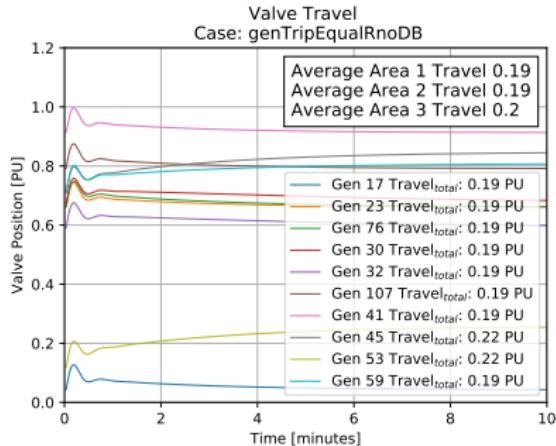


Area Droop and Valve Travel

Area 3 droop = 0.2



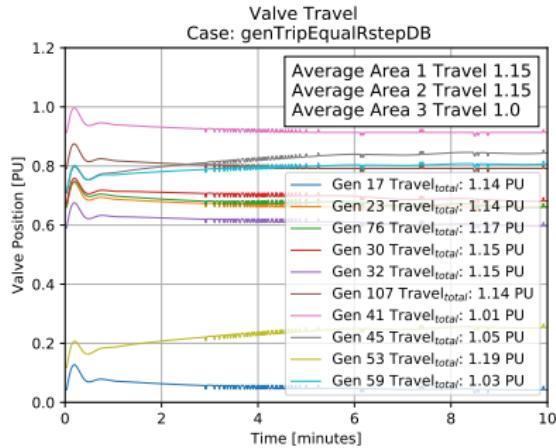
Area 3 droop = 0.05



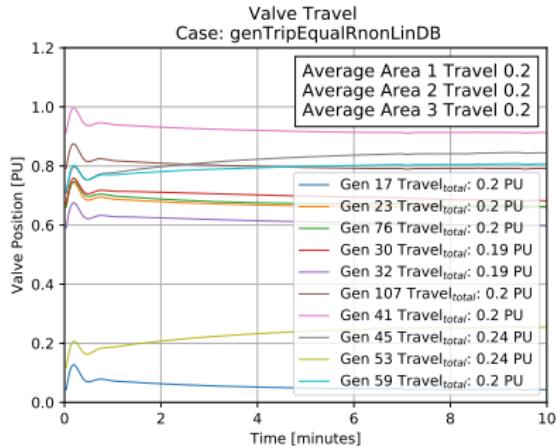
Quick Controller Test

Deadband and Valve Travel

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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