



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

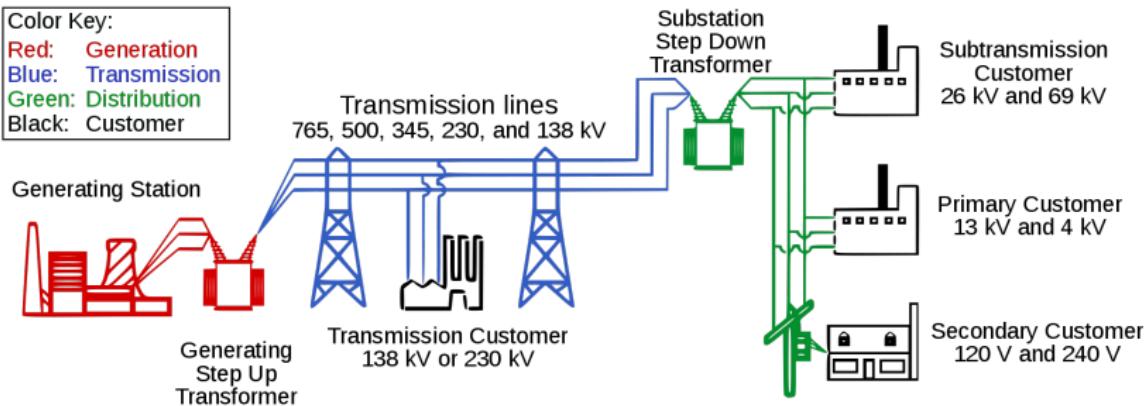
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Montana Technological University - Master's Thesis Research Project

October 22nd, 2019

What is a Power System?

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

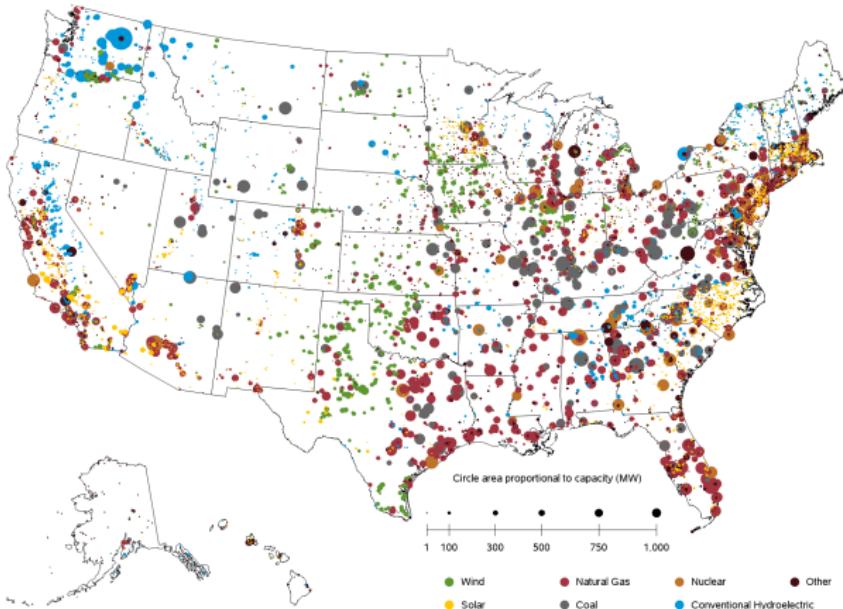


Electrical supply connected to demand.

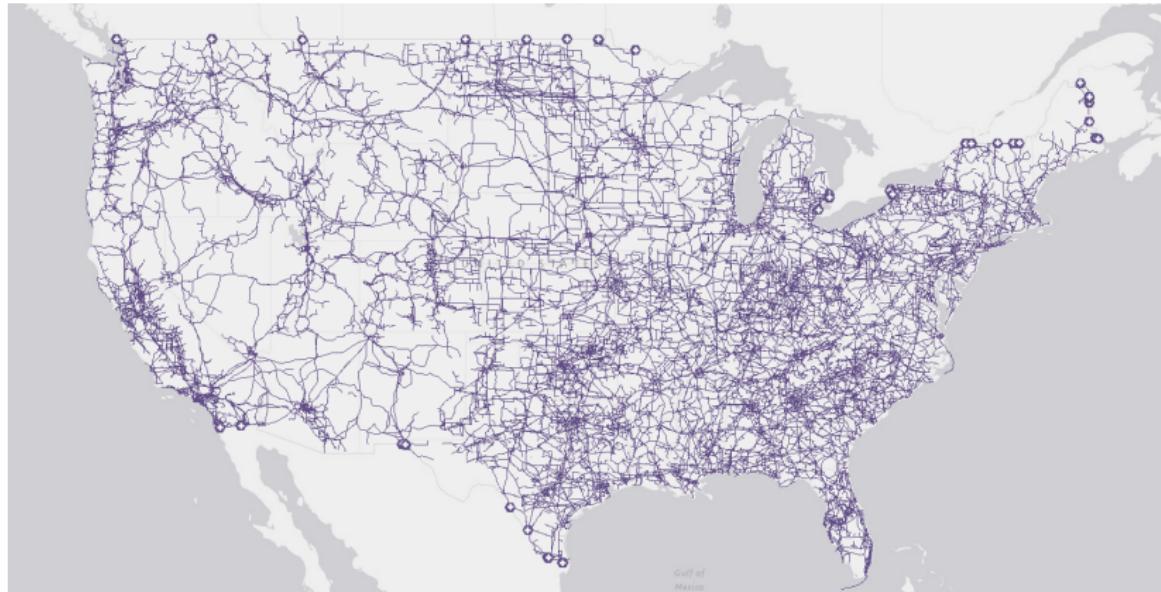
Physical Structure

U.S. Electric Generation

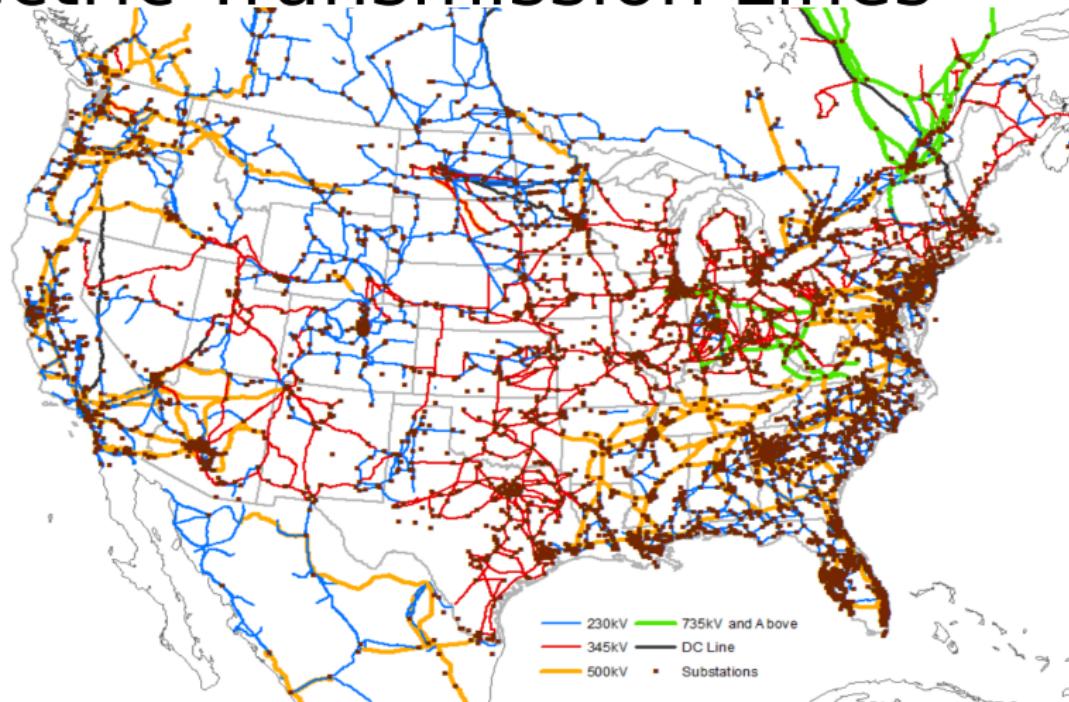
Operable utility-scale generating units as of July 2019



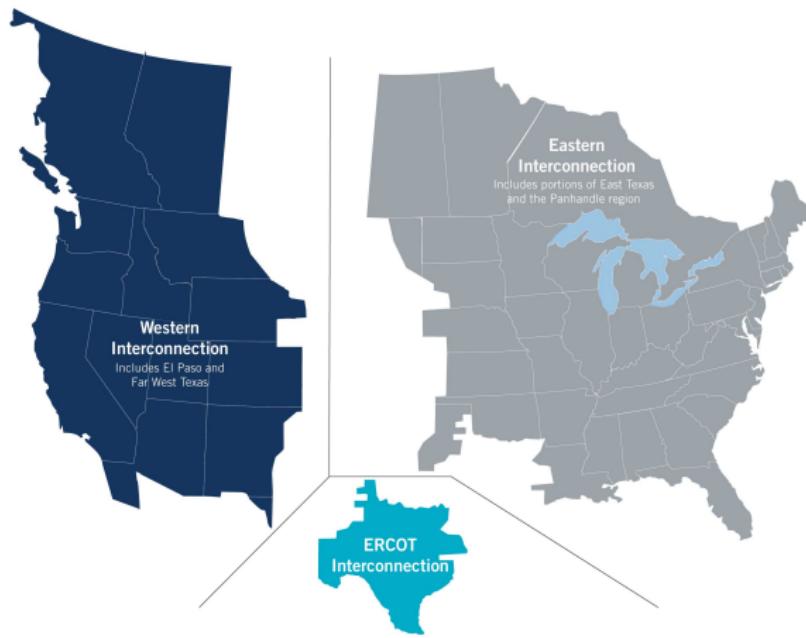
U.S. Electric Transmission Lines



Electric Transmission Lines

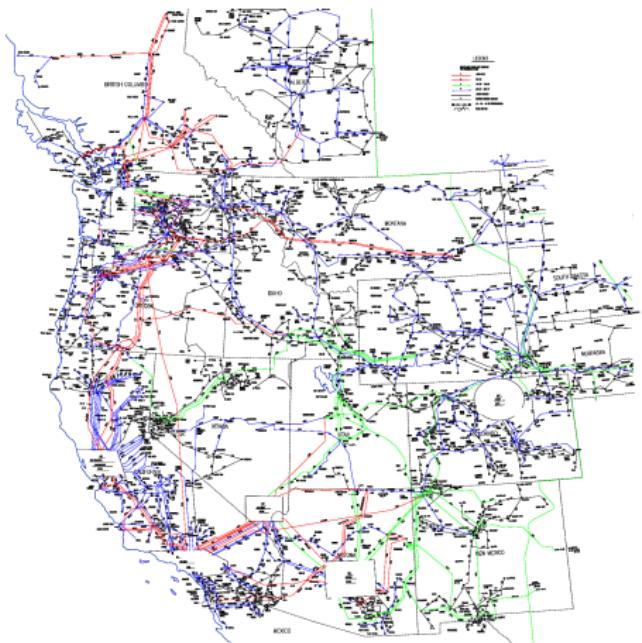


Interconnections



WECC Model

- ▶ 21,879 Buses
- ▶ 17,210 lines
- ▶ 4,231 Gens
- ▶ 11,048 Loads

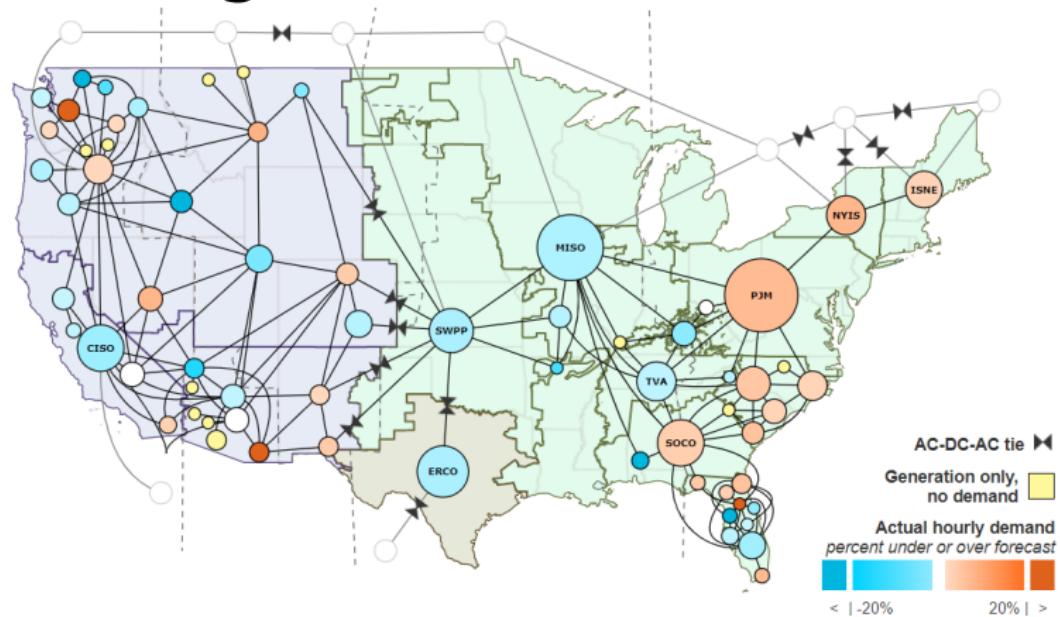




'People in Charge'

- ▶ **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.

Balancing Authorities (BAs)





Operational Structure

BA Action - Forecasting

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

megawatthours



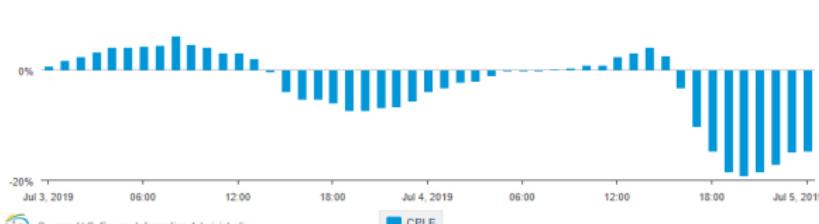
Balancing authority forecast error 06/27/2019 – 07/04/2019, EDT

percent deviation from forecast

20%

0%

-20%



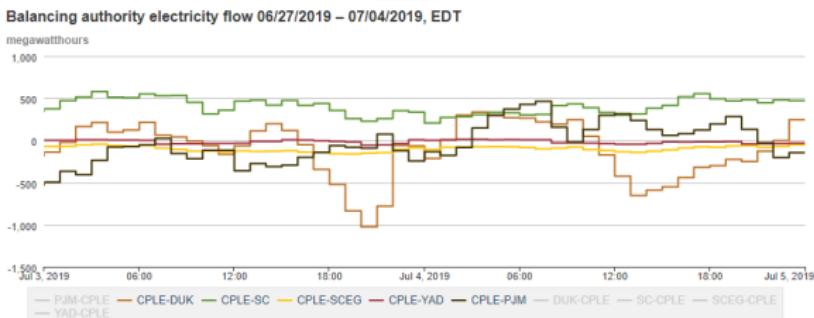
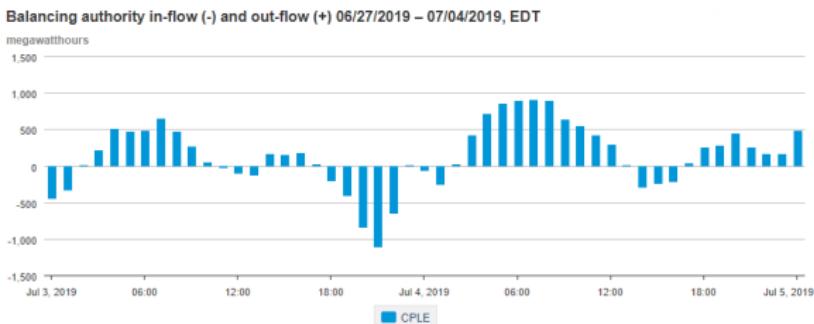
Source: U.S. Energy Information Administration





Operational Structure

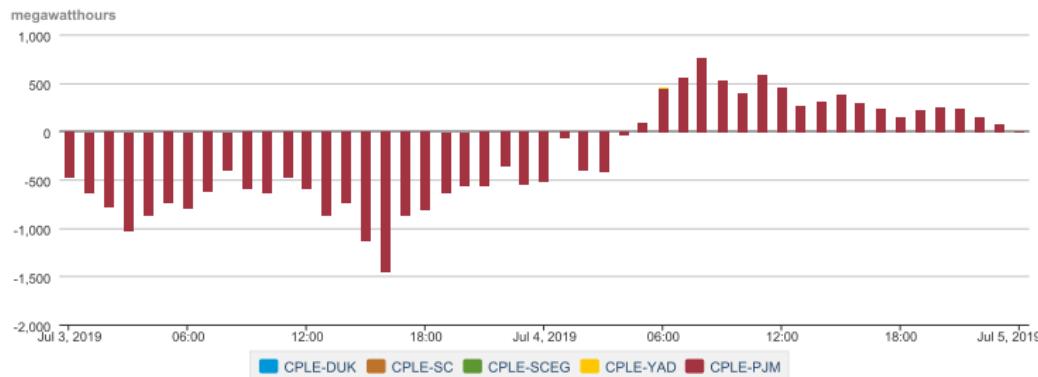
BA Action - Interchange



BA Action - Interchange Error

≈ Area Control Error

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

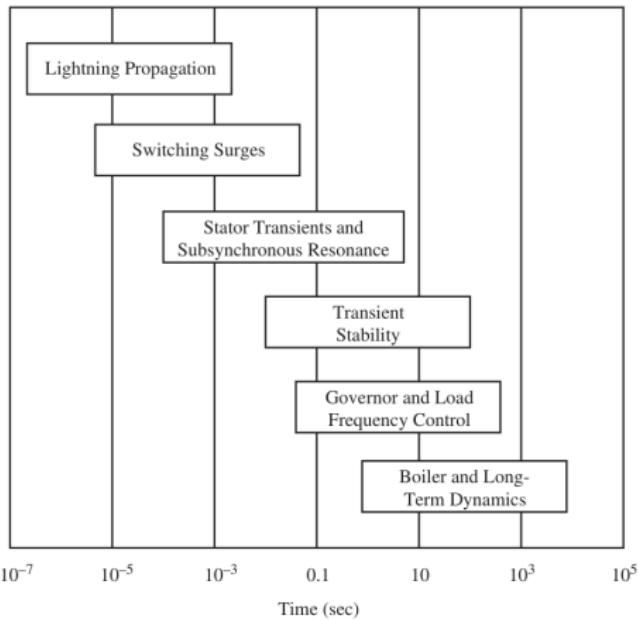


Source: U.S. Energy Information Administration

Explanation of Wording

What is Long-Term?

- ▶ 1 sec ↔ hours
∴
- ▶ 10→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

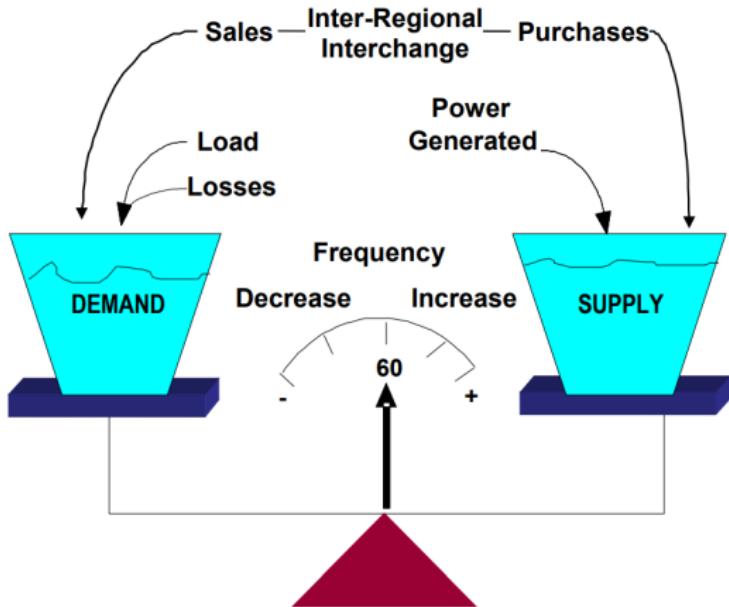
Frequency (ω)

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

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

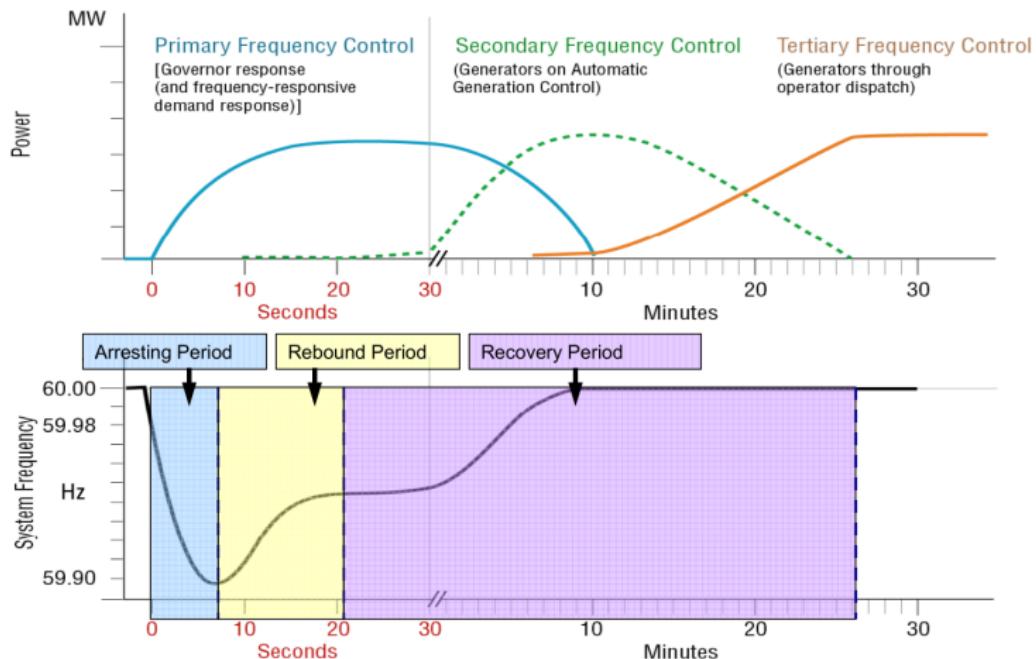
Electric demand
always met.

Demand always
changing.



Dynamic Concepts of Interest

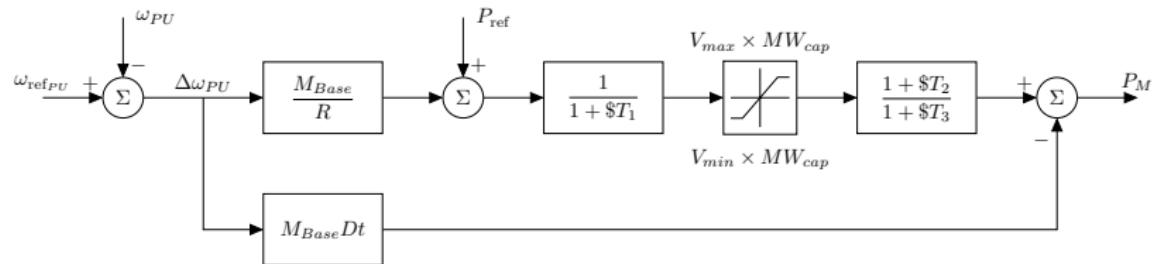
Automatic Controls



Turbine Speed Governors

Primary control.

Governors adjust turbine mechanical power to arrest frequency decline.

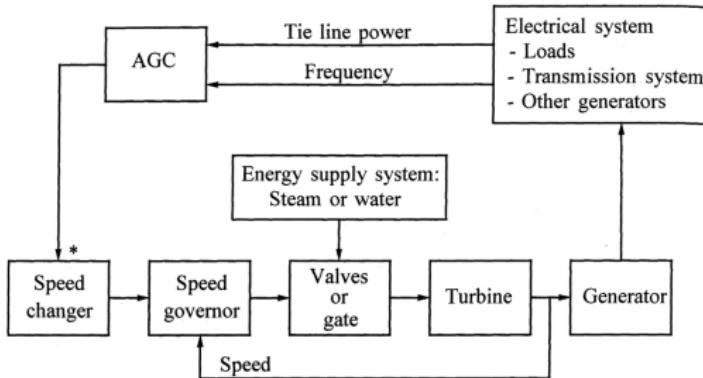


Dynamic Variable: Fuel Valve Position

Automatic Generation Control

Secondary Control.

Correct frequency and interchange error.



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Dynamic Variable: Area Control Error



Explanation of Computational Approach

What is a Power Flow?

A steady state solution to all bus voltages, bus voltage angles, and real and reactive power of a system.

A *snapshot* of a stable power system.

Power flows are not dynamic.



Explanation of Computational Approach

Time-Sequenced Power Flows?

Multiple power flows arranged in a way to give the allusion of time.

A *flip book of snapshots*.

Allows for additional dynamics to be calculated between *snaps*.
(i.e frequency, valve position, etc.)

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’.

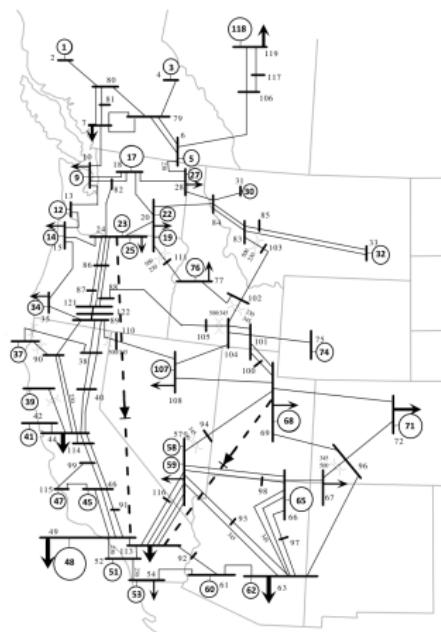
And why?

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.

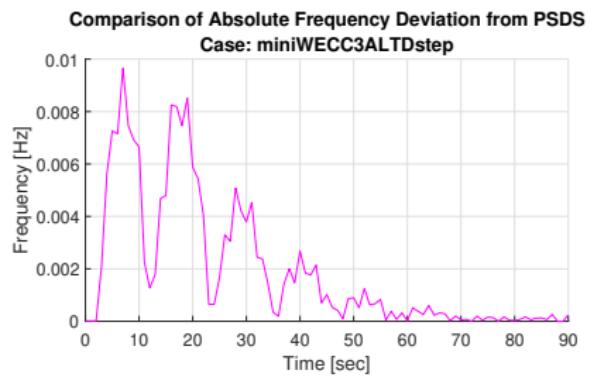
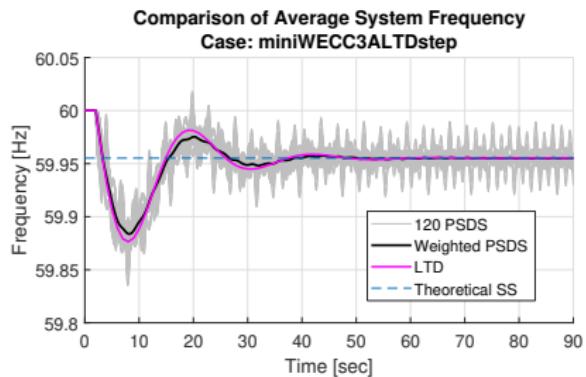
miniWECC Model

- ▶ 120 Buses
- ▶ 104 lines
- ▶ 34 Gens
- ▶ 23 Loads



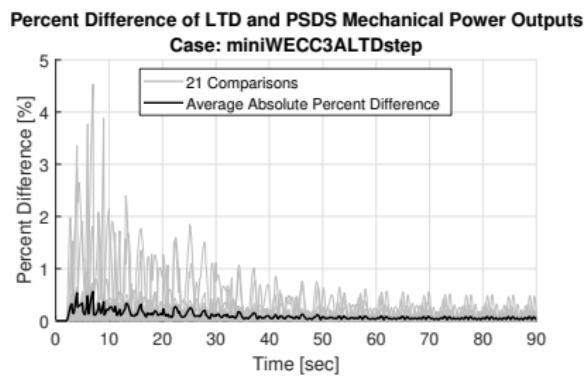
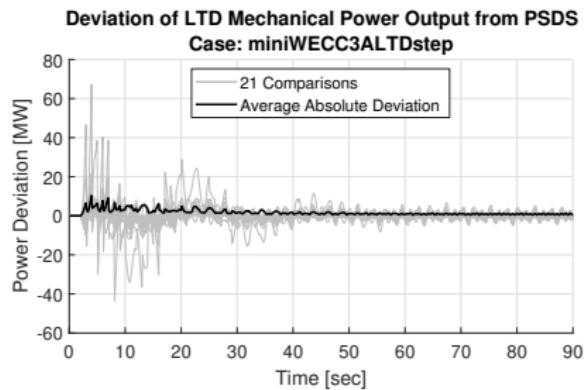
Step Perturbation Validation

400 MW Load Step Frequency Comparison



Step Perturbation Validation

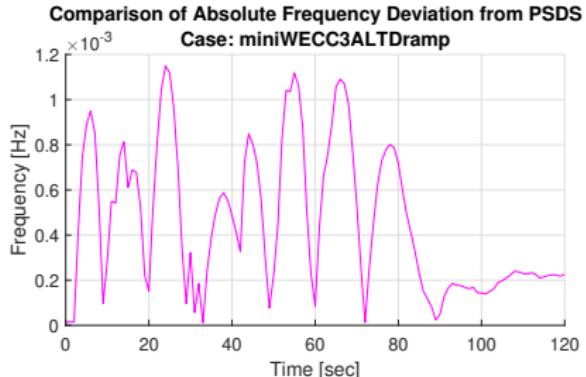
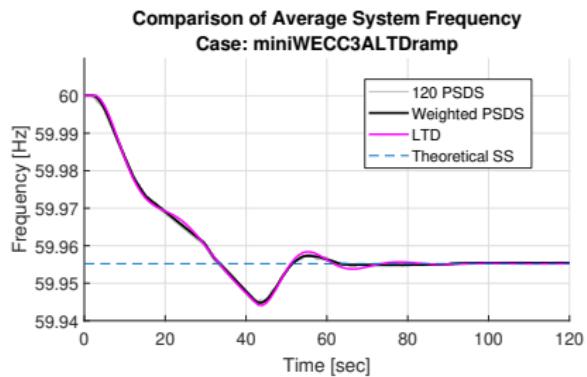
400 MW Load Step Mechanical Power Comparison



Quick Validation

Ramp Perturbation Validation

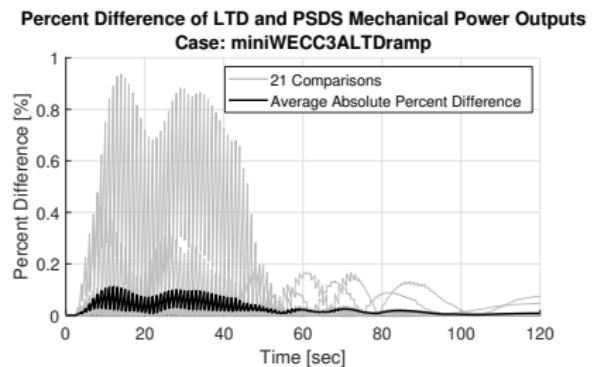
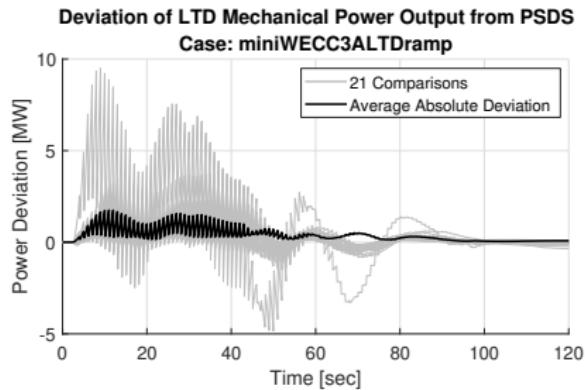
20 second 400 MW Load Ramp Frequency Comparison



Quick Validation

Ramp Perturbation Validation

20 second 400 MW Load ramp Mechanical Power Comparison



Governor Deadband Options

Pic of deadband options



Quick Controller Test

Governor Deadband Results

BA gov deadband action - do a step deadband, and ramp deadband for comparison
should see 'knocking' with step, assumed to be resolved with ramp...

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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