



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

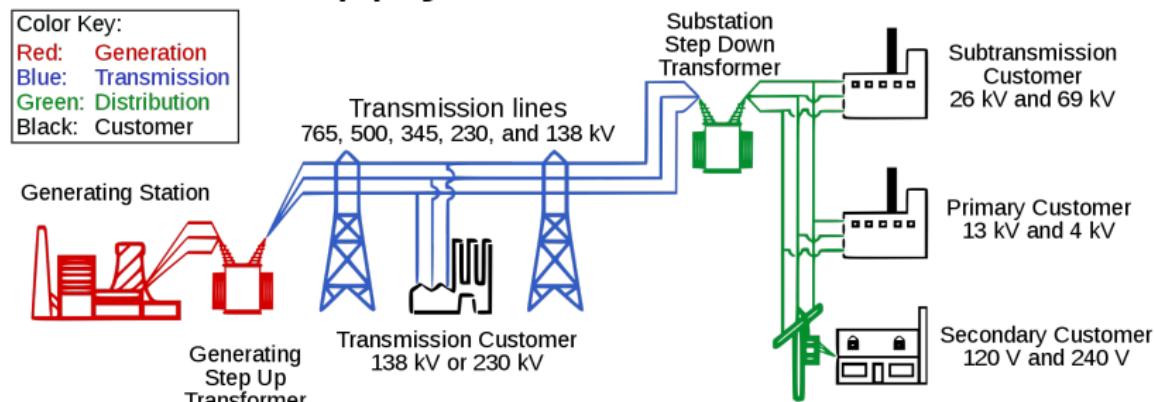
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Montana Technological University - Master's Thesis Research Project

October 22nd, 2019

# What is a Power System?

Electrical supply connected to demand.



[15]

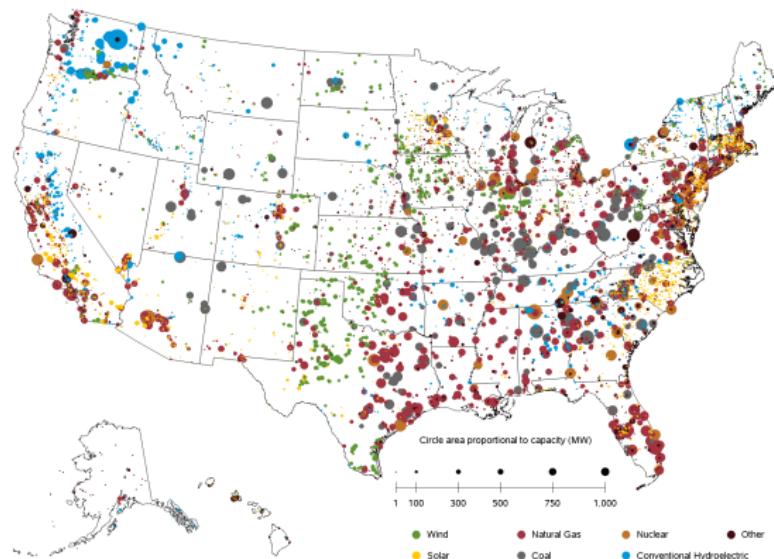
Research focus on transmission system.



## Physical Structure

## U.S. Electric Generation

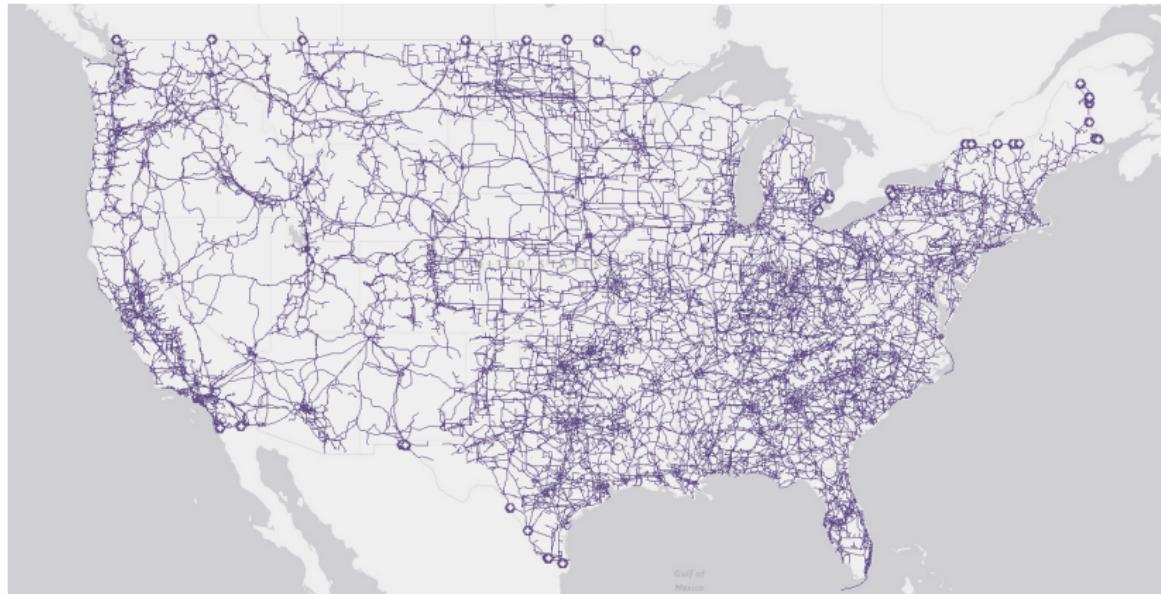
Operable utility-scale generating units as of July 2019



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."

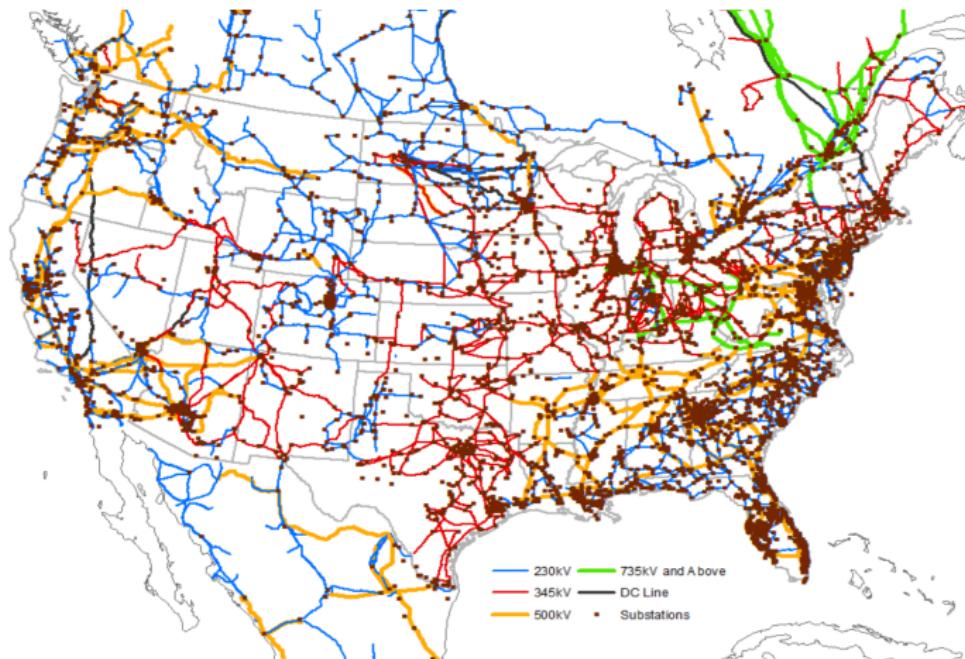
[16]

# U.S. Electric Transmission Lines



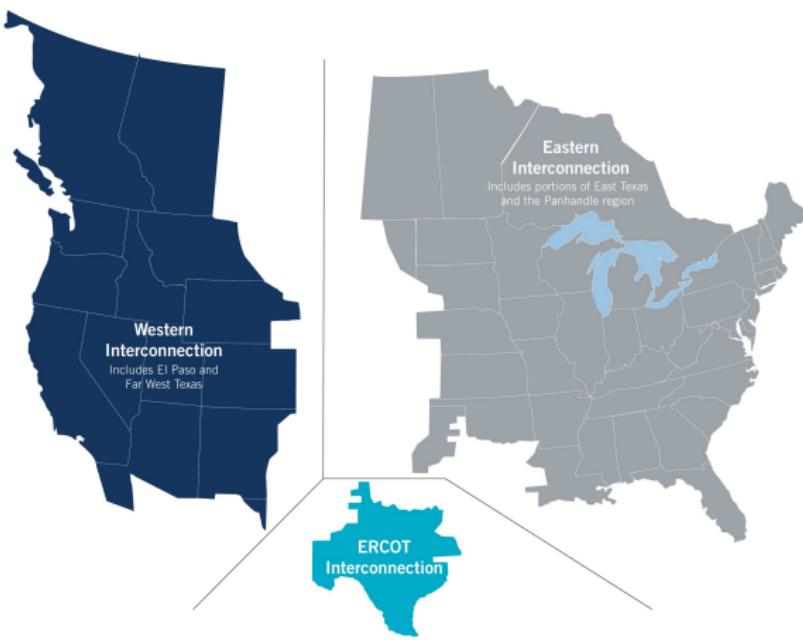
[28]

# Electric Transmission Lines



[21]

# Interconnections



[6]

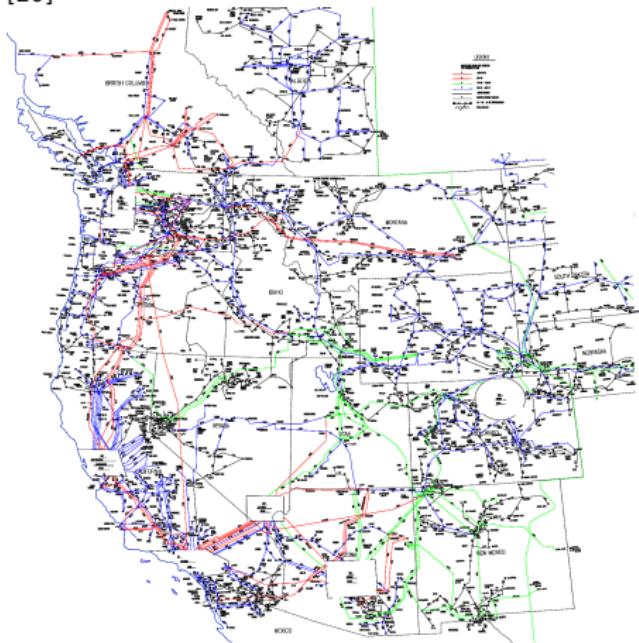
## Physical Structure

# Industry Software Model

WECC Model (GE PSLF)

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

[20]

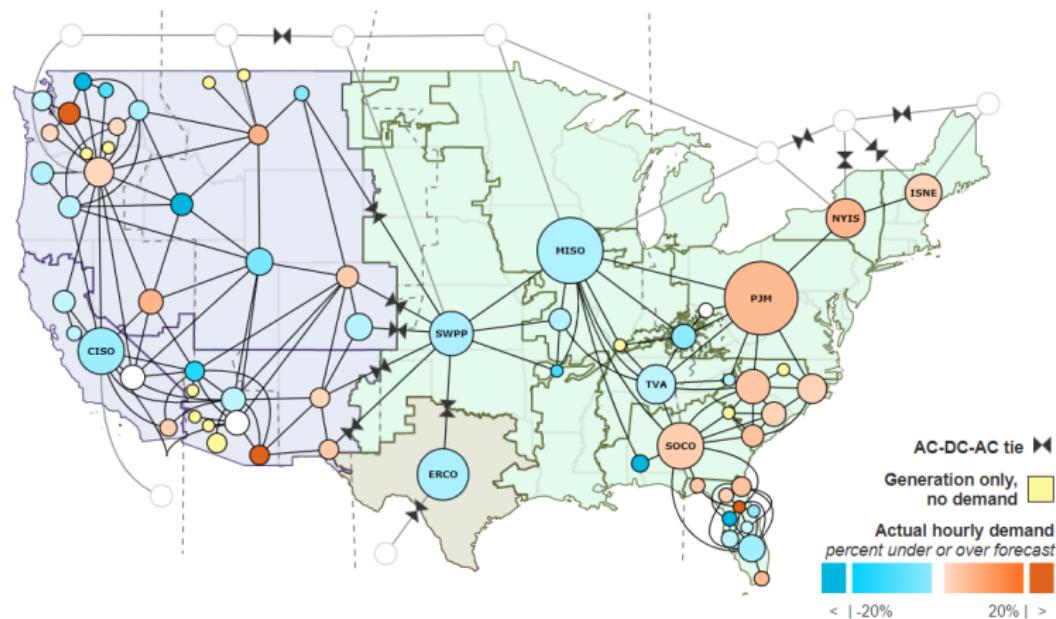




# 'People in Charge'

- ▶ **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.

# Balancing Authorities (BAs)



[27]



## Operational Structure

# BA Action - Forecasting

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

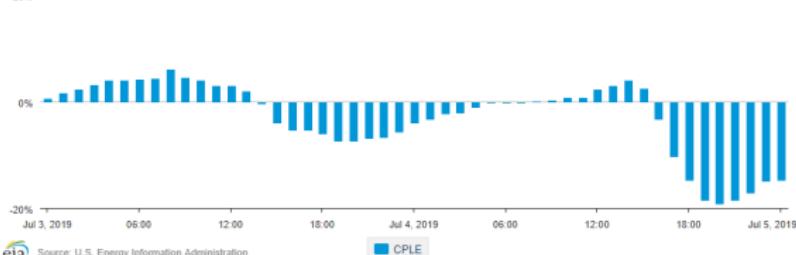
megawatthours



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

percent deviation from forecast

20%



Source: U.S. Energy Information Administration

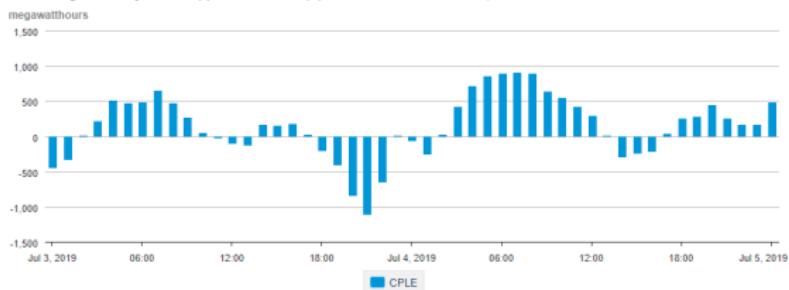
[27]



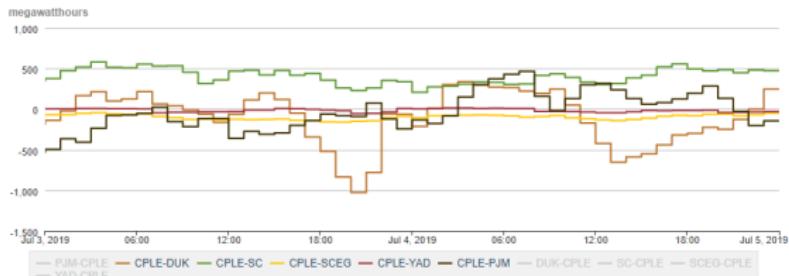
## Operational Structure

# BA Action - Interchange

Balancing authority in-flow (-) and out-flow (+) 06/27/2019 – 07/04/2019, EDT



Balancing authority electricity flow 06/27/2019 – 07/04/2019, EDT

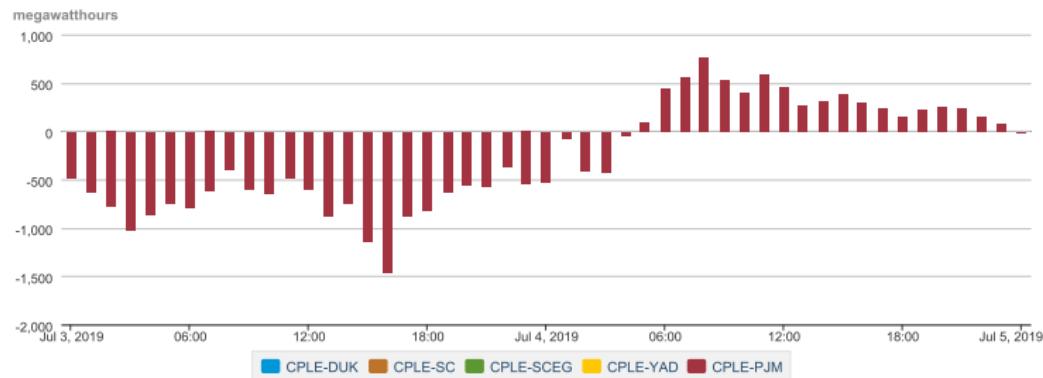


Source: U.S. Energy Information Administration

[27]

# BA Action - Error Tracking

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



Source: U.S. Energy Information Administration

[27]

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



Explanation of Wording

# What is Dynamic Simulation?

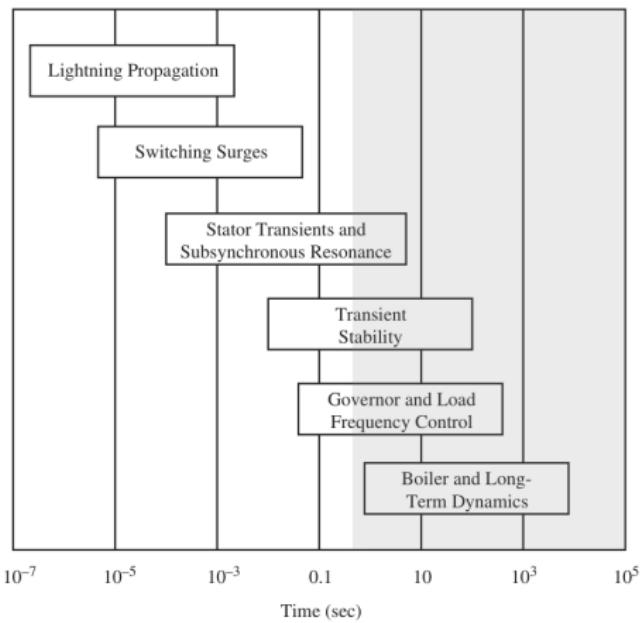
A computer's mathematical solution to how a system may change over time.

Think solving ODE's.

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

## Explanation of Wording

# What is Long-Term?

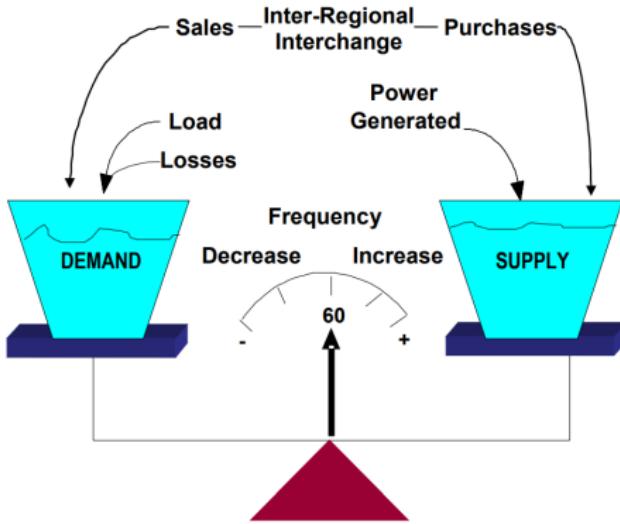


- 1 sec  $\leftrightarrow$  hours
- ⋮
- 10→60 minute simulations
- 1 sec time step

# Frequency ( $\omega$ )

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

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



Electric load always met.

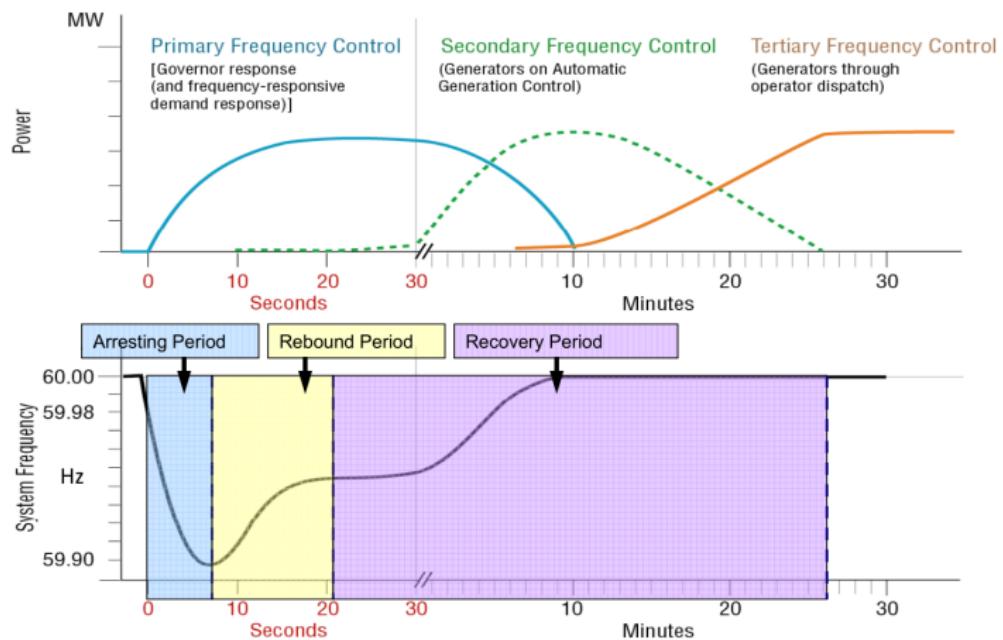
[25]

Load and losses always changing.



## Dynamic Concepts of Interest

## Automatic Controls

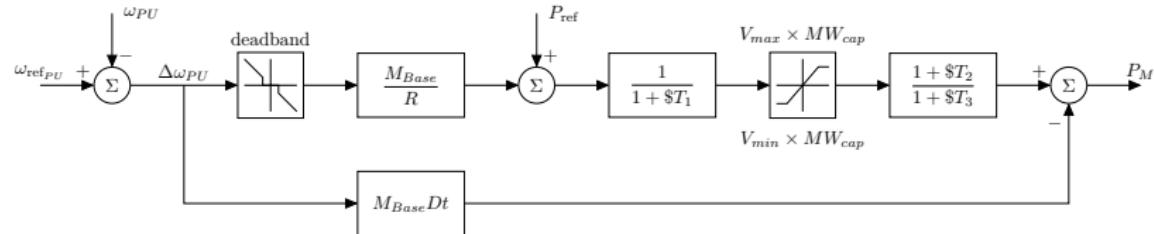


# Turbine Speed Governors

## Primary Control

Purpose: Adjust turbine mechanical power to arrest frequency decline.

Dynamic Variable: Fuel Valve Position

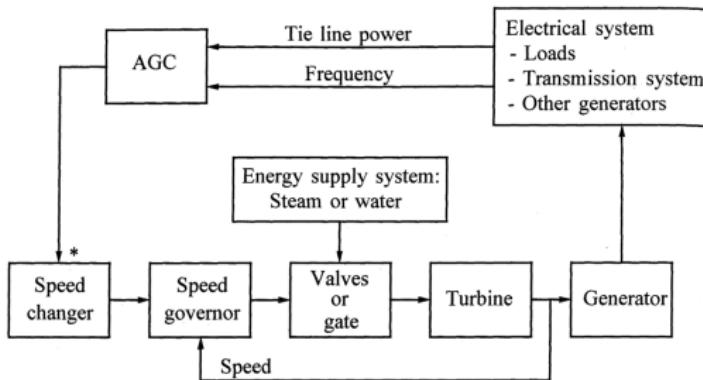


# Automatic Generation Control (AGC)

Secondary Control

Purpose: Eliminate Area Control Error

Dynamic Variable: Area Control Error

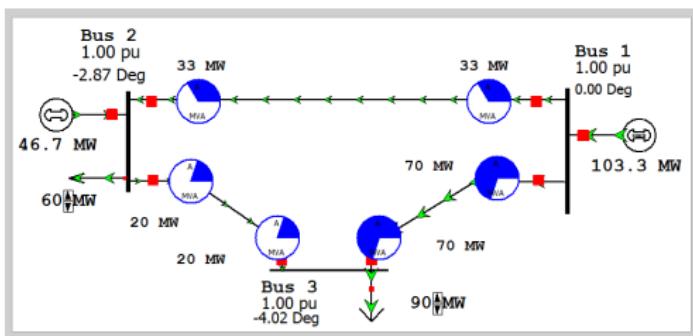


\* AGC applied only to selected units

[18]

# What is a Power Flow?

A steady state power system solution.



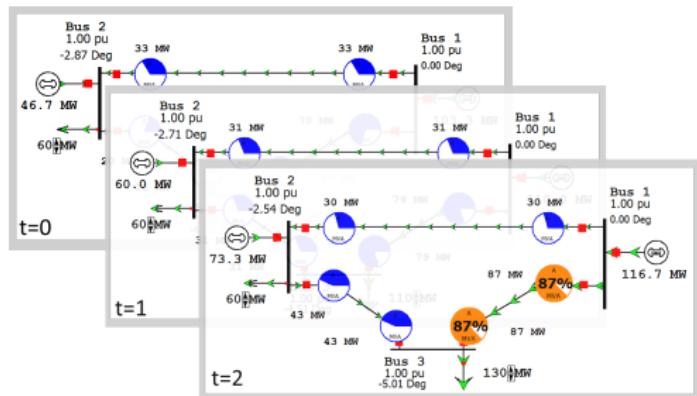
Software exists to solve power flows.  
Power flows are not dynamic.



Explanation of Computational Approach

# Time-Sequenced Power Flows?

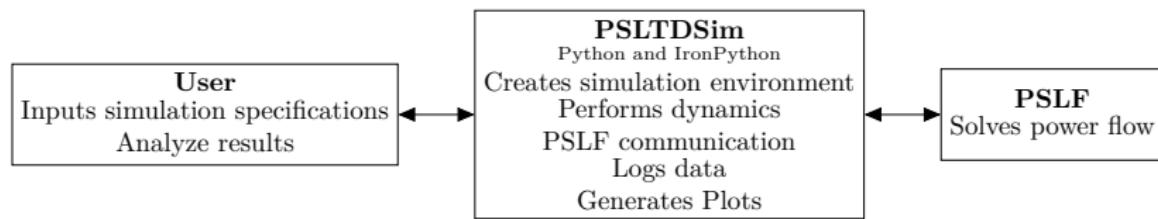
Power flows arranged in sequence to give the illusion of time.



## Software does not exist.

Explanation of Computational Approach

# 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:

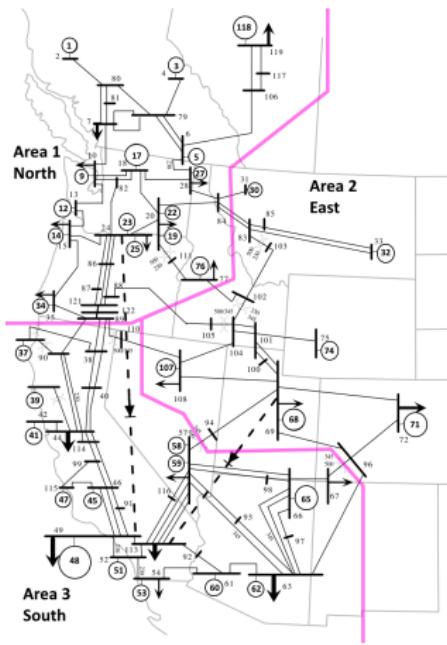
- ▶ Long-term events (i.e. Wind Ramps)
- ▶ Multi-Area Power Interactions
  - ▶ Governor and AGC settings and interactions
- ▶ Ways to reduce machine effort while meeting reliability standards.

## Quick Validation

# Validation Software Model

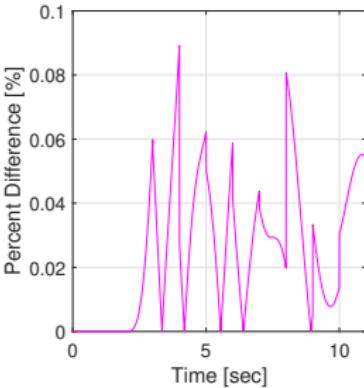
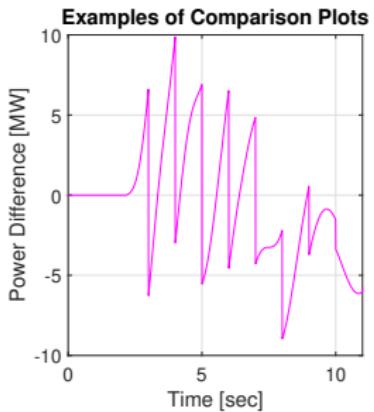
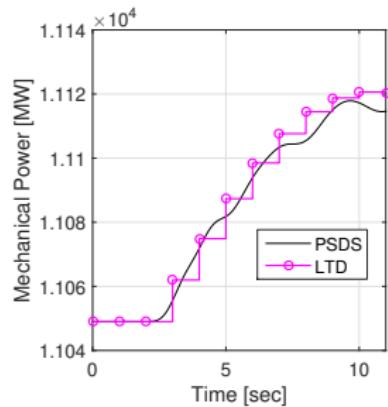
miniWECC

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



[13]

# Plot Explanation



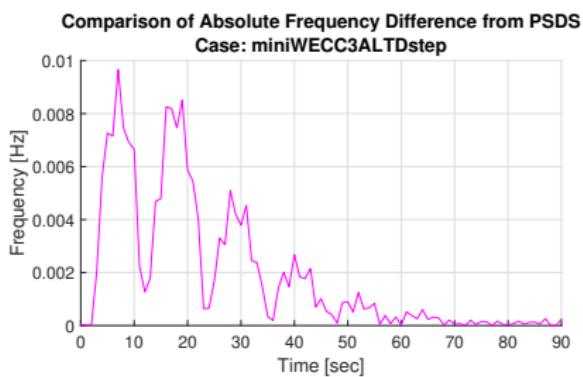
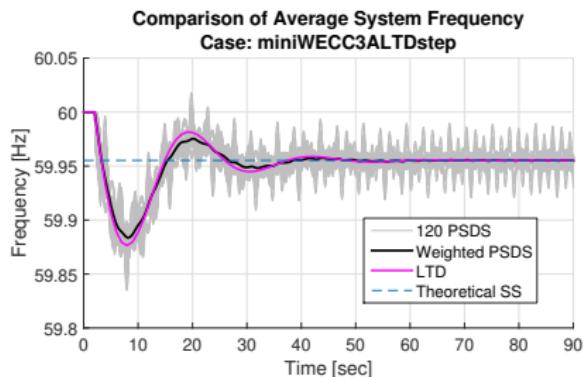
$$\text{PSDS}_{data} - \text{LTD}_{data} = \text{Difference}_{data}$$

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

Quick Validation

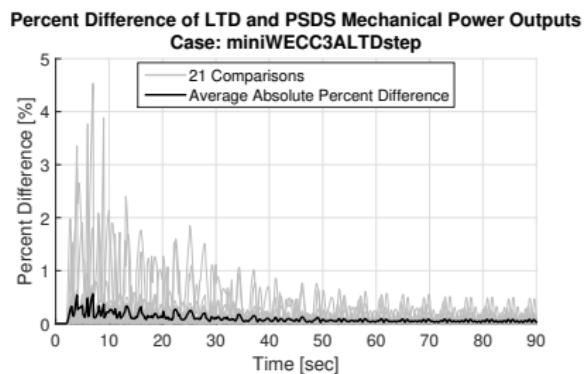
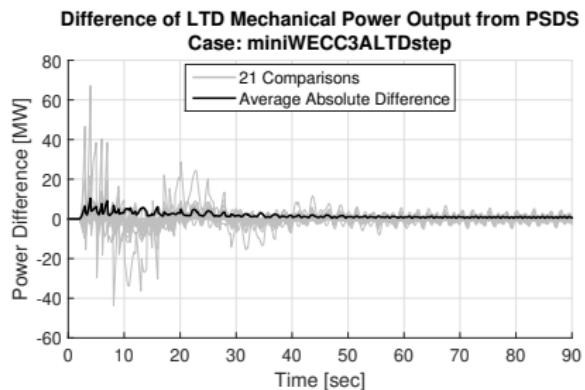
# Step Perturbation Validation

## 400 MW Load Step Frequency Comparison



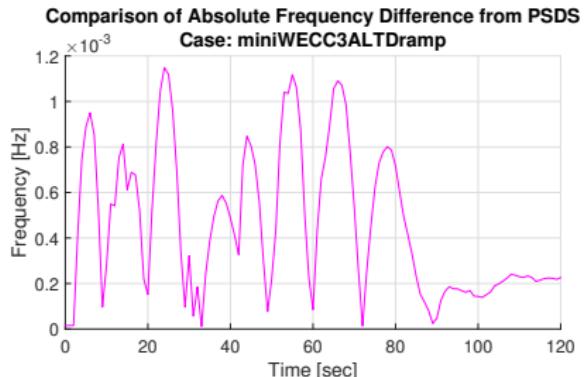
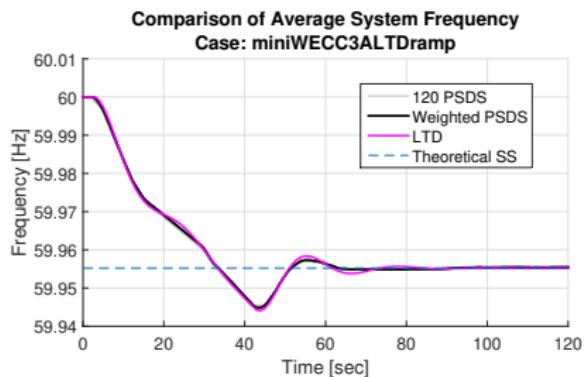
# Step Perturbation Validation

## 400 MW Load Step Mechanical Power Comparison



# Ramp Perturbation Validation

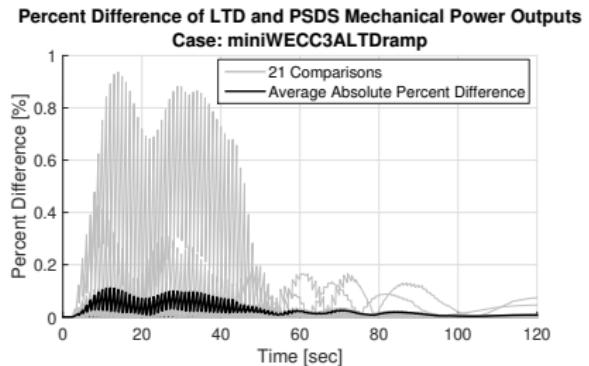
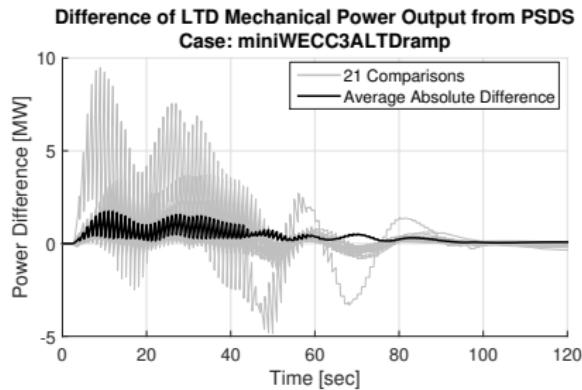
## 20 second 400 MW Load Ramp Frequency Comparison



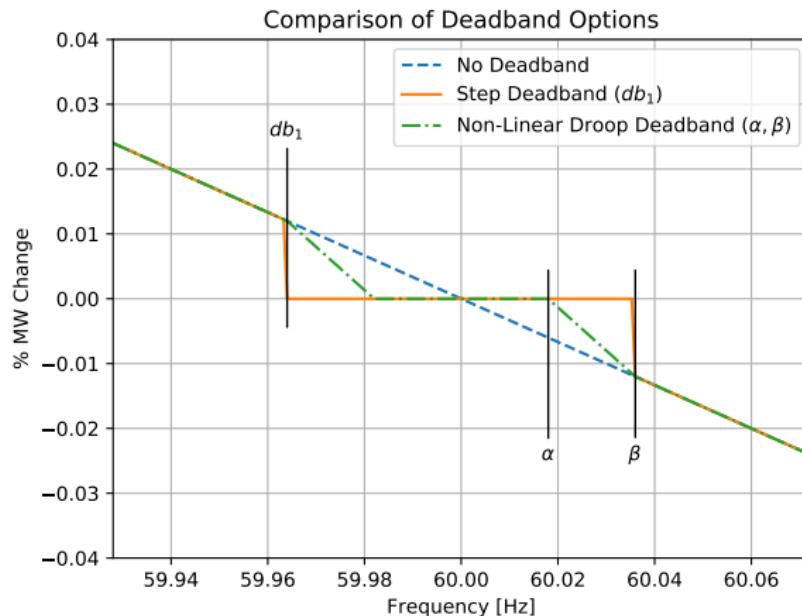
Quick Validation

# Ramp Perturbation Validation

## 20 second 400 MW Load ramp Mechanical Power Comparison



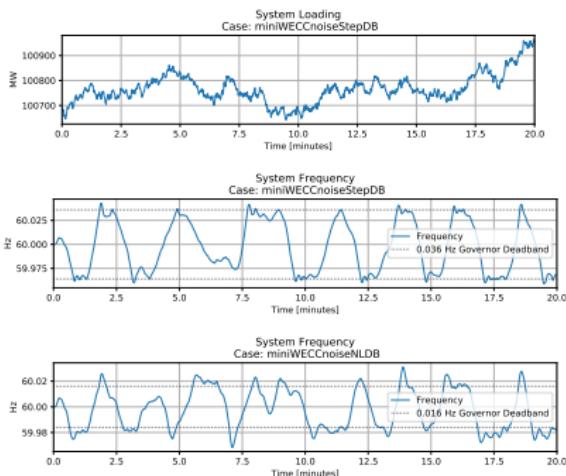
# Governor Deadband



## Quick Controller Test

# Noise Test

20 Minutes of 0.05% Noise on all loads



| Generator | Valve Travel [PU] | Movement Reduction |
|-----------|-------------------|--------------------|
|           | Step DB           | N-LD DB            |
| 17        | 0.87              | 0.24               |
| 23        | 0.94              | 0.25               |
| 76        | 0.86              | 0.23               |
| 30        | 0.96              | 0.27               |
| 32        | 0.94              | 0.26               |
| 107       | 0.86              | 0.23               |
| 41        | 0.20              | 0.06               |
| 45        | 0.33              | 0.12               |
| 53        | 1.00              | 0.27               |
| 59        | 0.29              | 0.09               |
| 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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