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

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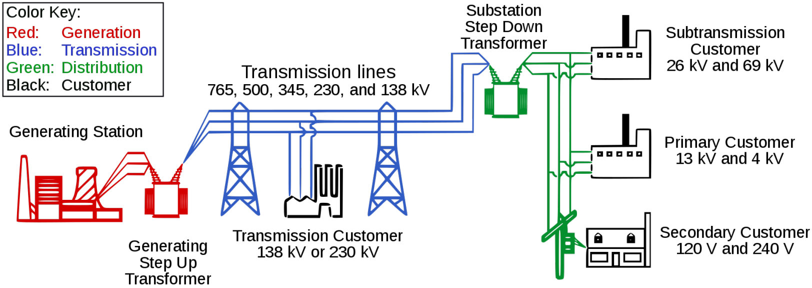
Montana Technological University - Master’s Thesis Research Project

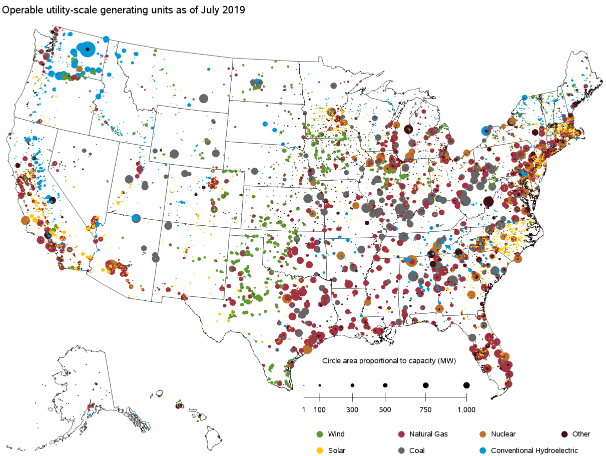
October 22nd, 2019

# What is a Power System?

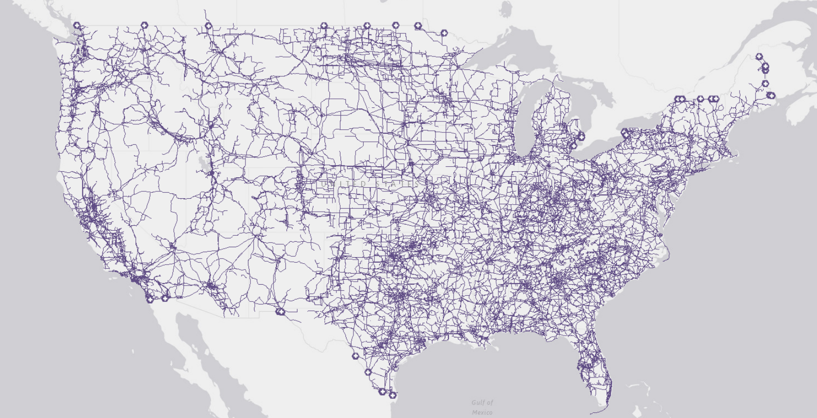



Electrical supply connected to demand.

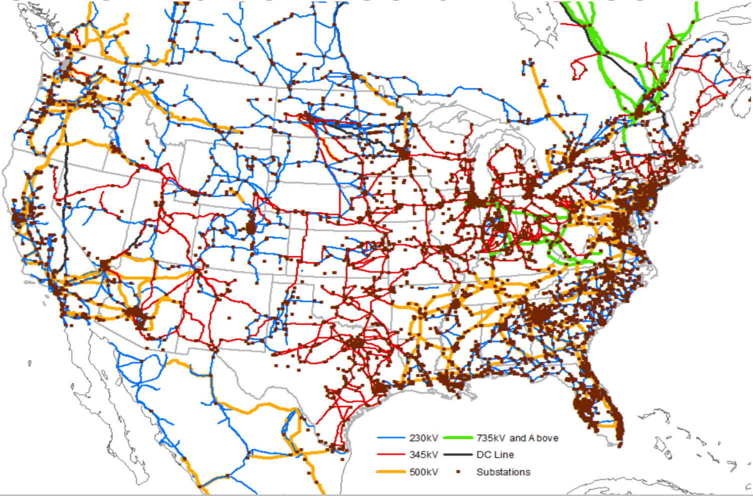
# U.S. Electric Generation



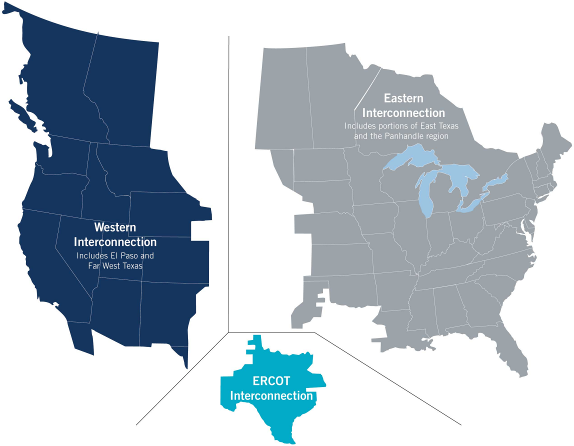
# U.S. Electric Transmission Lines



# Electric Transmission Lines



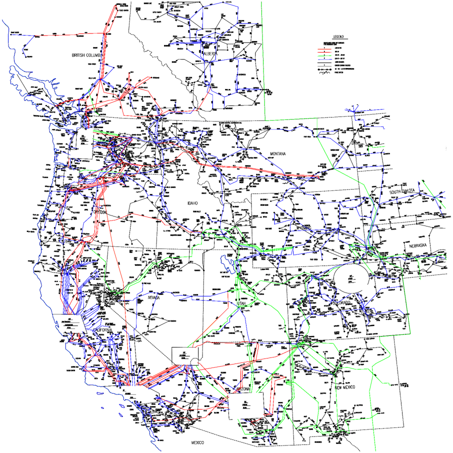
# Interconnections



# Industry Software Model

## WECC Model

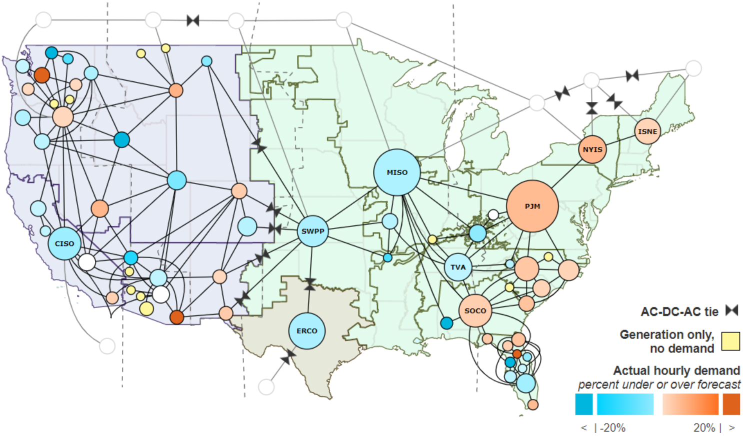
- 4,231 Generators
- 17,210 Lines
- 22 Areas
- 11,048 Loads
- 21,879 Buses



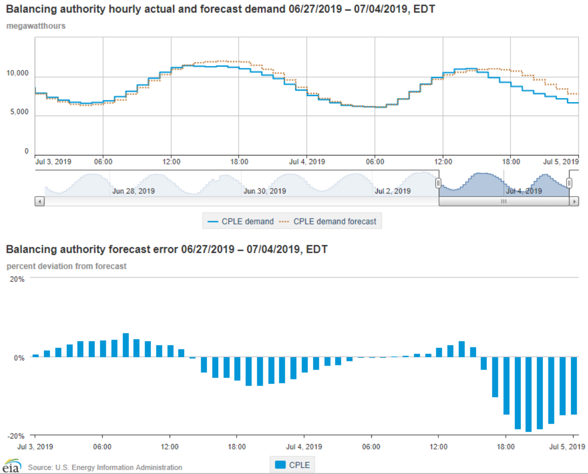
# ‘People in Charge’

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

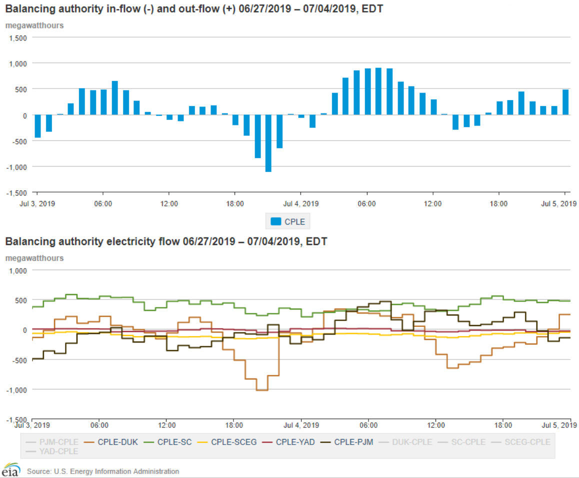
# Balancing Authorities (BAs)



# BA Action - Forcasting

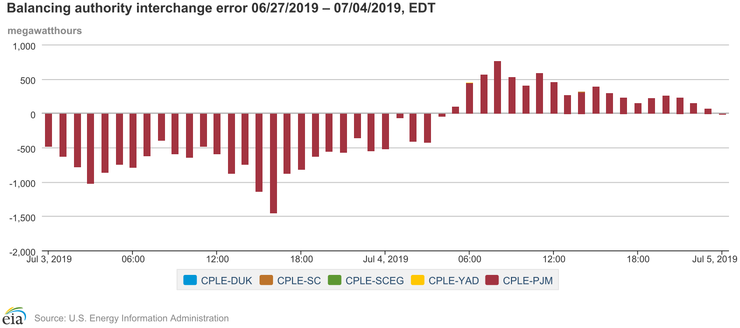


# BA Action - Interchange

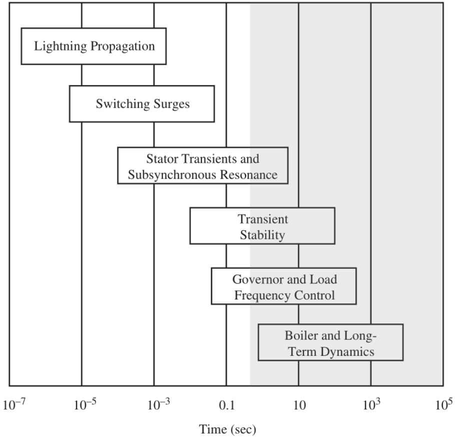


# BA Action - Interchange Error

## ≈ Area Control Error



# 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.

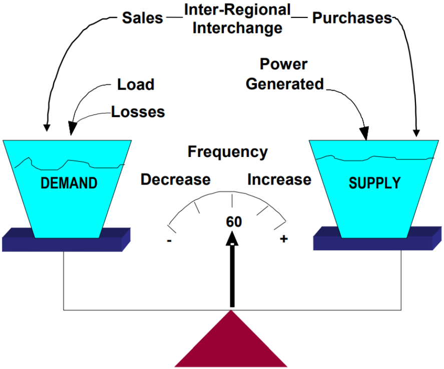
Think solving ODE's.

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

# Frequency ($\omega$)

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

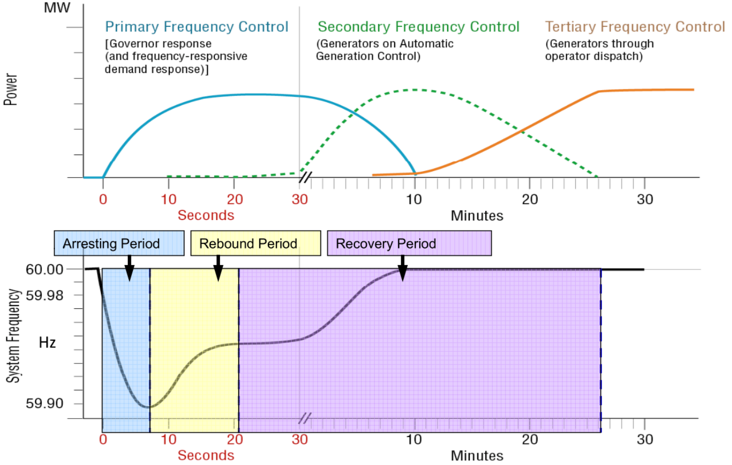
$$P_{acc} = P_{gen} - P_{load}$$




Electric load always met.

Load and losses always changing.

# Automatic Controls

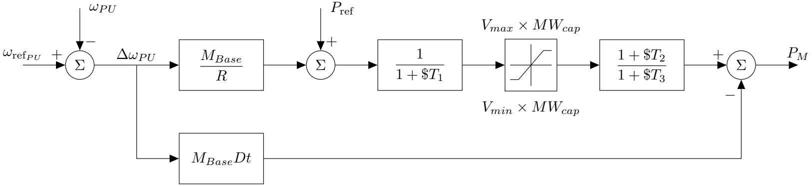


# Turbine Speed Governors

## Primary Control

Purpose: Adjust turbine mechanical power to arrest frequency decline.

Dynamic Variable: Fuel Valve Position

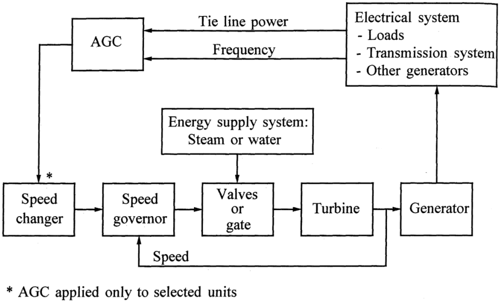


# Automatic Generation Control

## Secondary Control

Purpose: Eliminate Area Control Error

Dynamic Variable: Area Control Error

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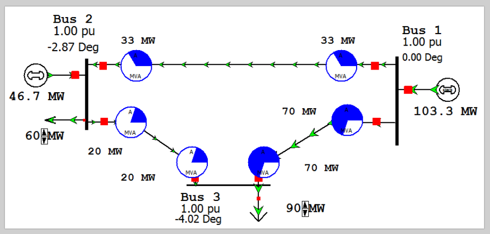
# What is a Power Flow?

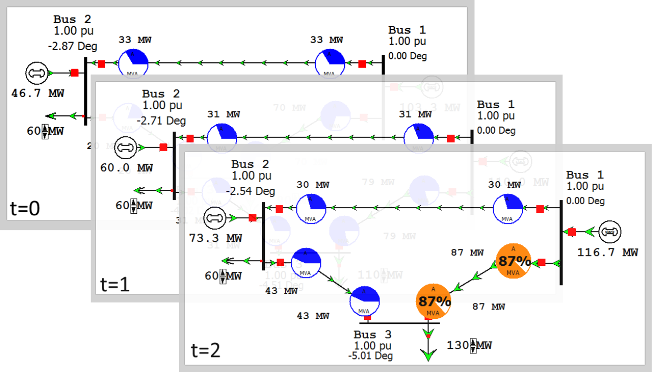
A steady state power system solution.
A *snapshot* of a stable power system.




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?

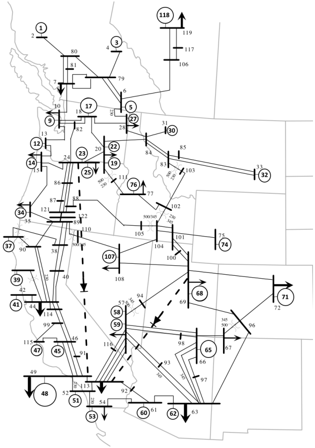
To study engineering problems involving:

- 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.

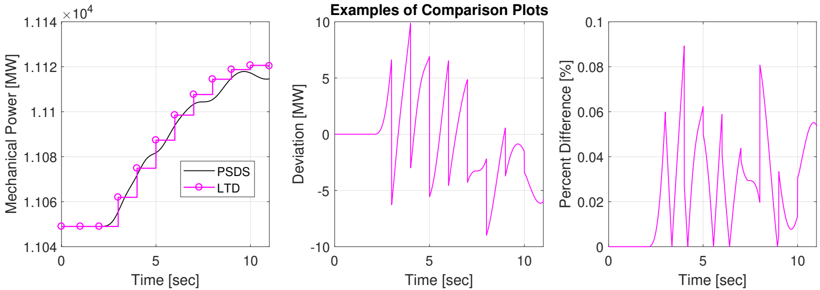
# Software Model

## miniWECC

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



# Plot Explanation

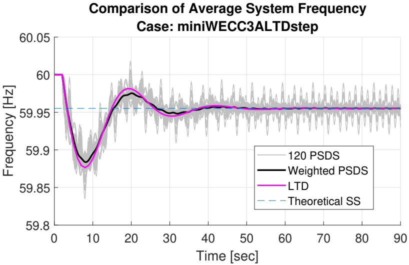


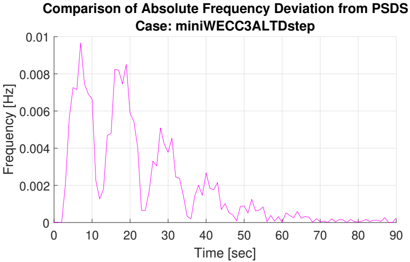

$$\text{PSDS}_{data} - \text{LTD}_{data} = \text{Deviation}_{data}$$

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

# Step Perturbance Validation

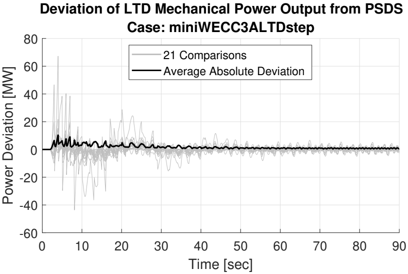
## 400 MW Load Step Frequency Comparison

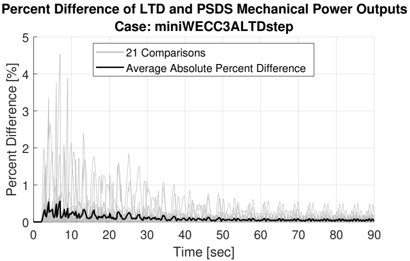


# Step Perturbance Validation

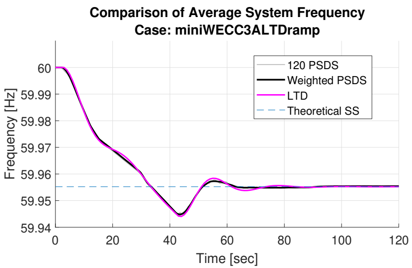
## 400 MW Load Step Mechanical Power Comparison

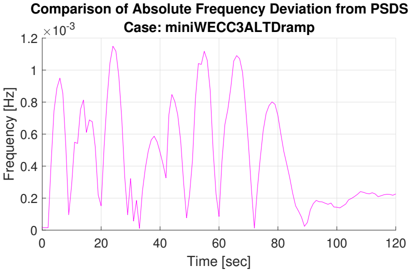


# Ramp Perturbance Validation

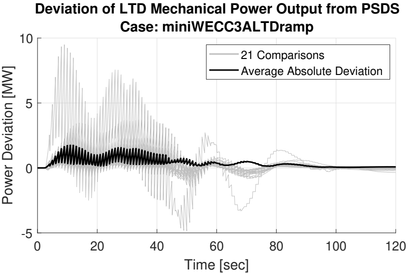
## 20 second 400 MW Load Ramp Frequency Comparison

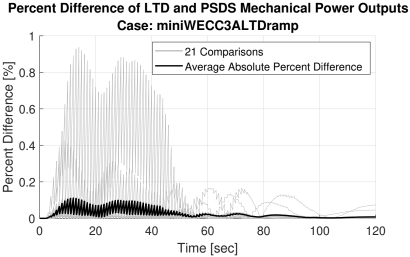


# Ramp Perturbance Validation

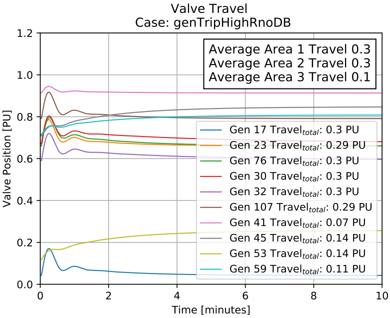
## 20 second 400 MW Load ramp Mechanical Power Comparison



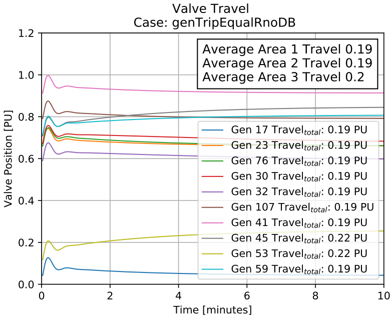



# Area Droop and Valve Travel

Area 3 droop = 0.2

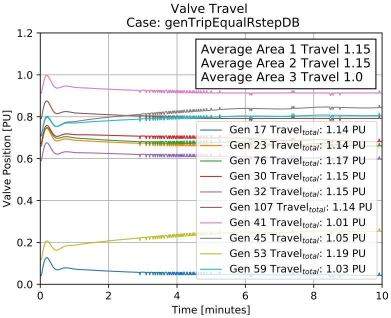



Area 3 droop = 0.05

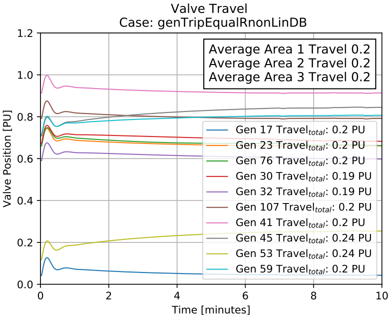


# Deadband and Valve Travel

## 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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