

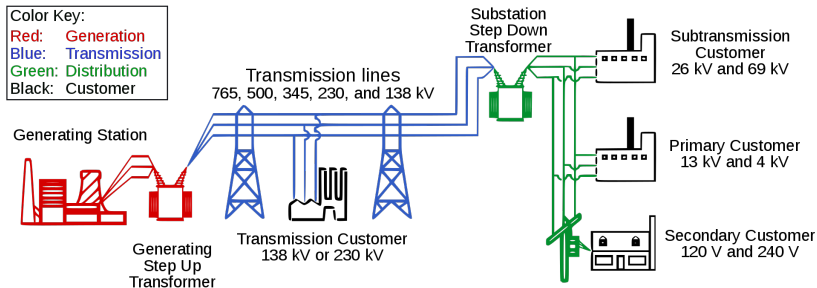
Power System Long-Term Dynamic Simulation using Time-Sequenced Power Flows

Thad Haines

Montana Technological University - Master's Thesis Research Project

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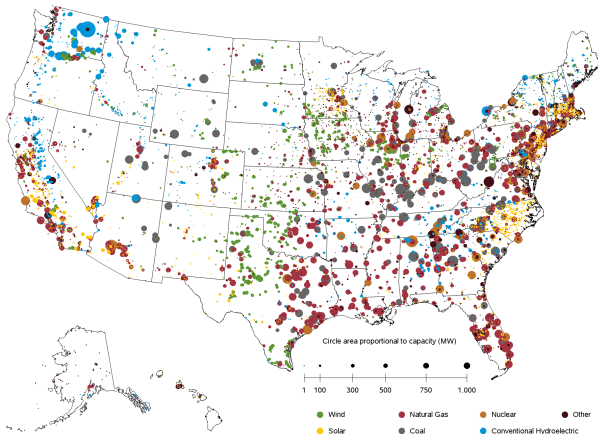
What is a Power System?



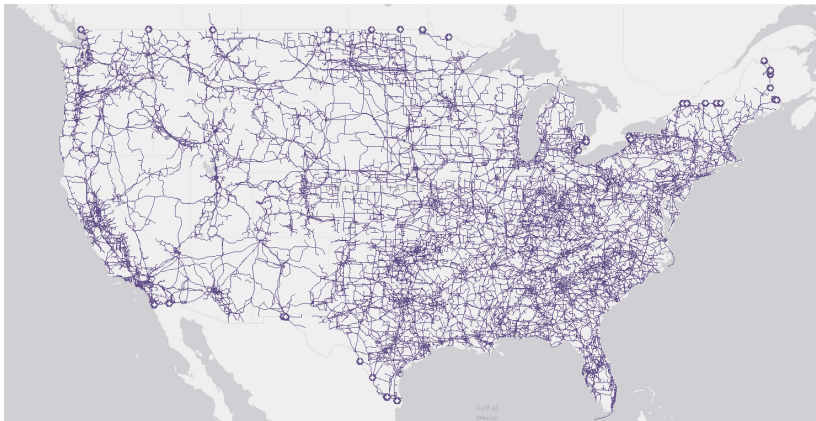
Electrical supply connected to demand.

U.S. Electric Generation

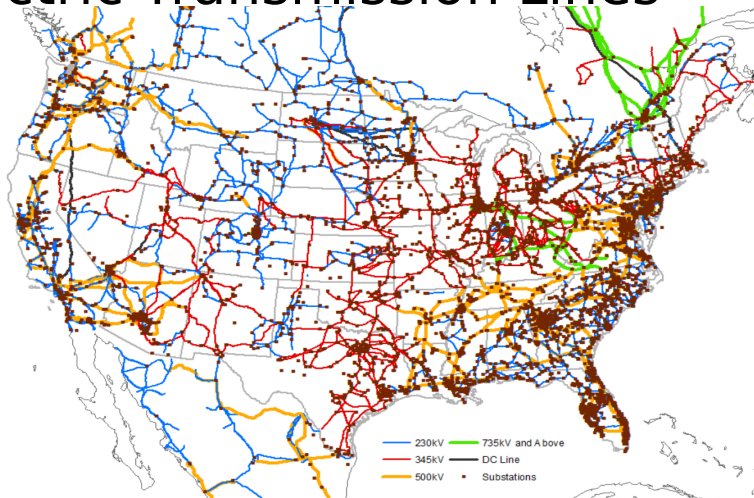
Operable utility-scale generating units as of July 2019



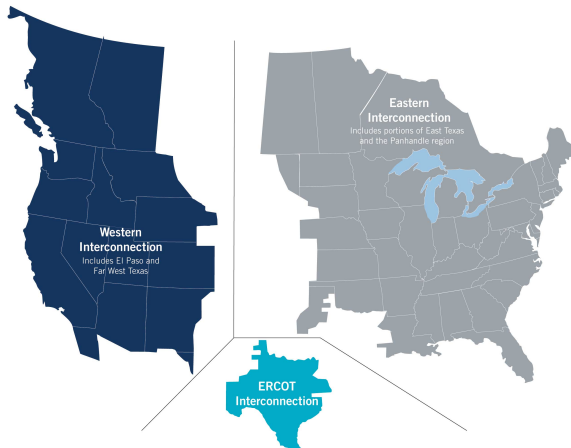
U.S. Electric Transmission Lines



Electric Transmission Lines

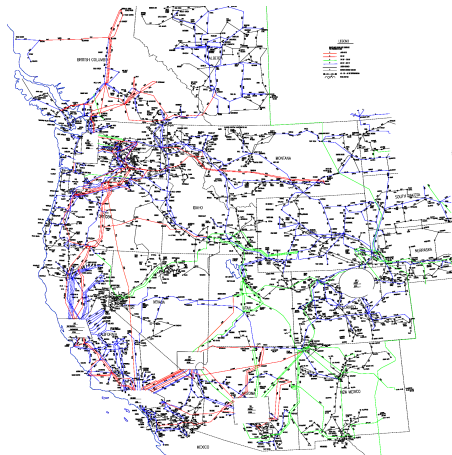


Interconnections



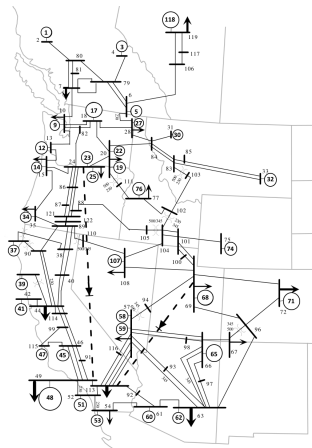
WECC Model

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



miniWECC Model

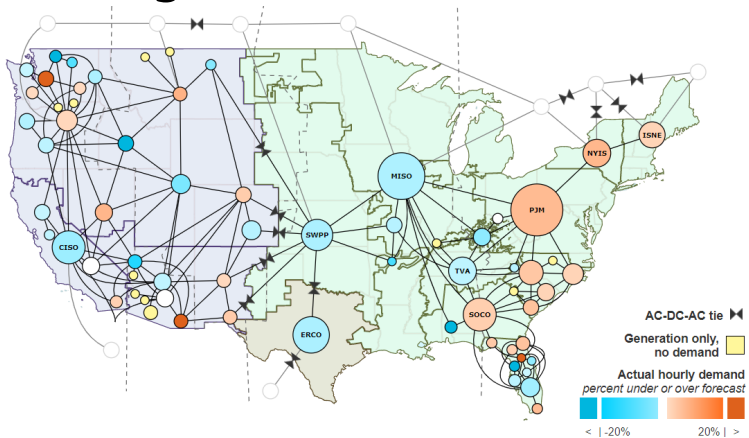
- ▶ 120 Buses
- ▶ 104 lines
- ▶ 34 Gens
- ▶ 23 Loads



‘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 Authorities** (BAs)
Manage specific portions of the power system to balance supply and demand and maintain mandatory operating conditions set by FERC and NERC.

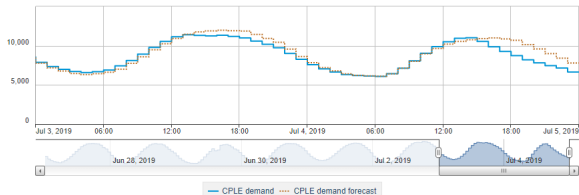
Balancing Authorities



BA Action - Forecasting

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

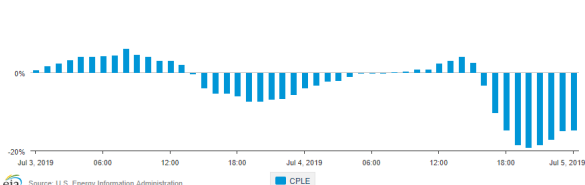
megawatthours



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

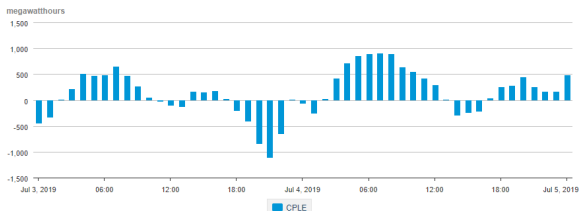
percent deviation from forecast

20%

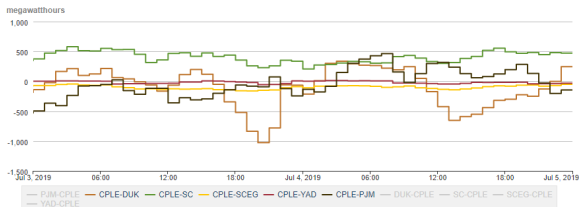


BA Action - Interchange

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

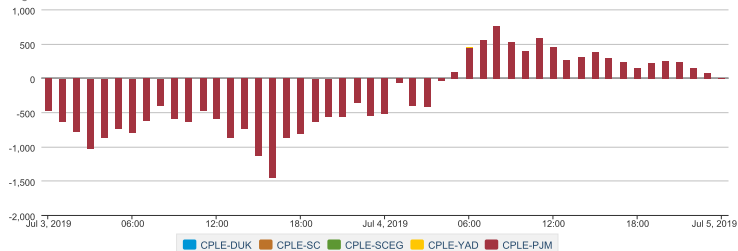


BA Action - Interchange Error

≈ Area Control Error

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

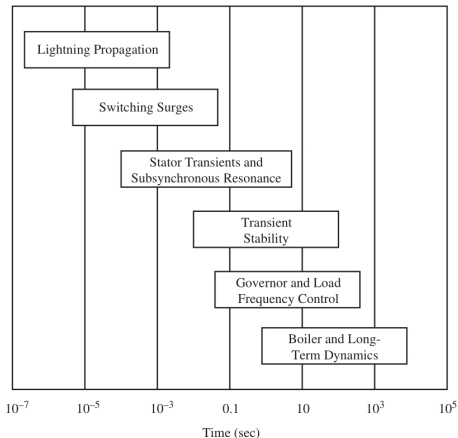
megawatthours



Source: U.S. Energy Information Administration

What is Long-Term?

- ▶ 1 sec \leftrightarrow hours
- ∴
- ▶ 10→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 perturbation.

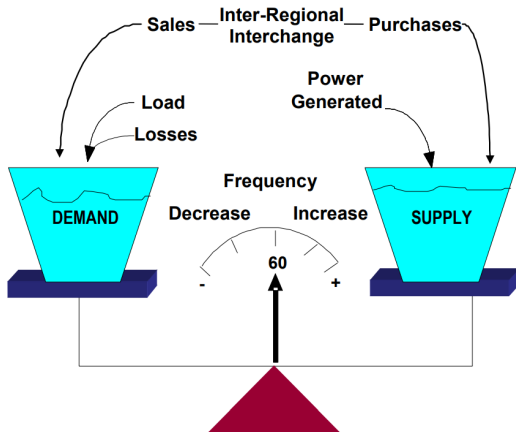
Frequency (ω)

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

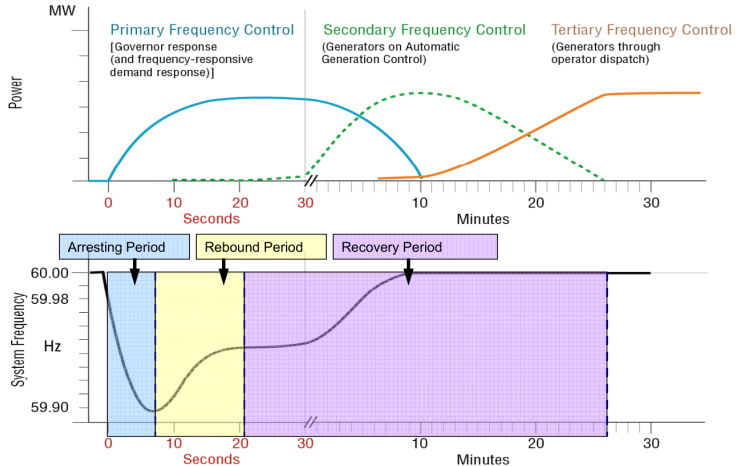
$$P_{acc} = P_{gen} - P_{load}$$

Electric demand
always met.

Demand always
changing.



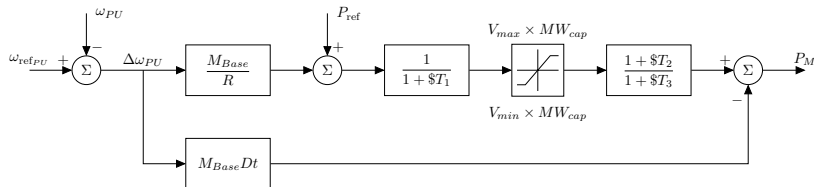
Automatic Controls



Turbine Speed Governors

Primary control.

Governors adjust turbine mechanical power to arrest frequency decline.

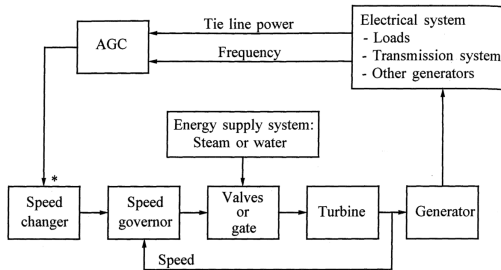


Dynamic Variable: Fuel Valve Position

Automatic Generation Control

Secondary Control.

Correct frequency and interchange error.



* AGC applied only to selected units

[13]

Dynamic Variable: Area Control Error

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.

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 *snap*s.
(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.

Quick Initial Validation

pictures of step event comparisons of ltd
vs psds

Quick Controller Test

BA controller action - do a with and without thing?

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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