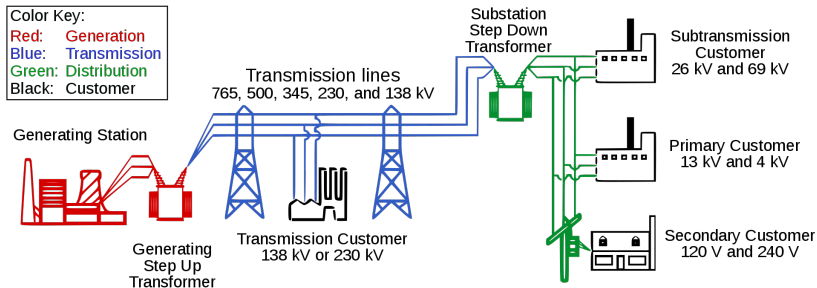# Power System Long-Term Dynamic Simulation using Time-Sequenced Power Flows

Thad Haines

Montana Technological University - Master's Thesis Research Project
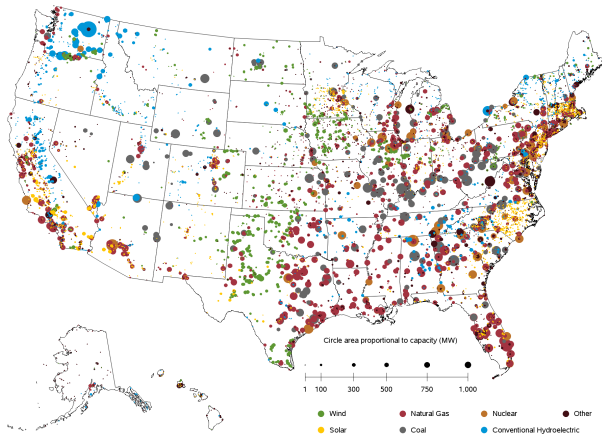
October 22nd, 2019

Power System   Long-Term Dynamics   Time-Sequenced Power Flows   Recap   Quick Results   Final Bits   References

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Physical Structure

What is a Power System?

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

Generating Station

Transmission lines
765, 500, 345, 230, and 138 kV

Generating Step Up Transformer

Transmission Customer
138 kV or 230 kV

Substation Step Down Transformer

Subtransmission Customer
26 kV and 69 kV

Primary Customer
13 kV and 4 kV

Secondary Customer
120 V and 240 V

Electrical supply connected to demand.

Power System Long-Term Dynamics Time-Sequenced Power Flows   Recap   Quick Results   Final Bits   References
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○ ○ ○ ○ ○ ○ ○ ○   ○ ○ ○ ○   ○
                                                      ○

Physical Structure

U.S. Electric Generation

Operable utility-scale generating units as of July 2019

Circle area proportional to capacity (MW)

1 100   300   500   750   1,000

● Wind   ● Natural Gas   ● Nuclear   ● Other
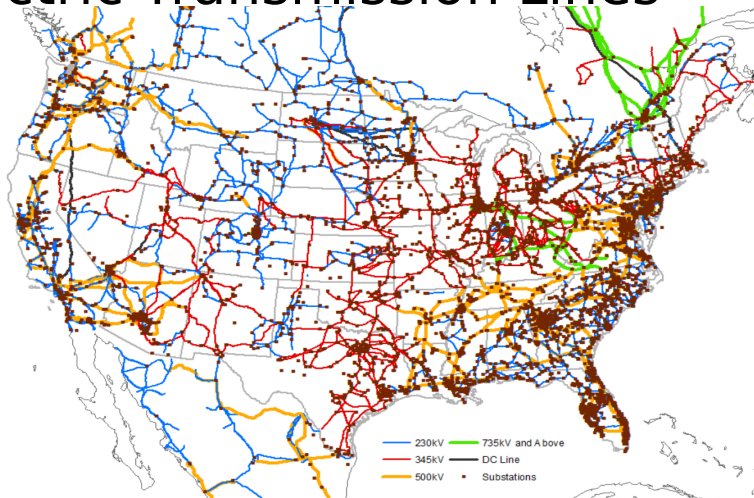● Solar   ● Coal   ● Conventional Hydroelectric

Sources: U.S. Energy Information Administration, Form EIA-860, 'Annual Electric Generator Report' and Form EIA-860M, 'Monthly Update to the
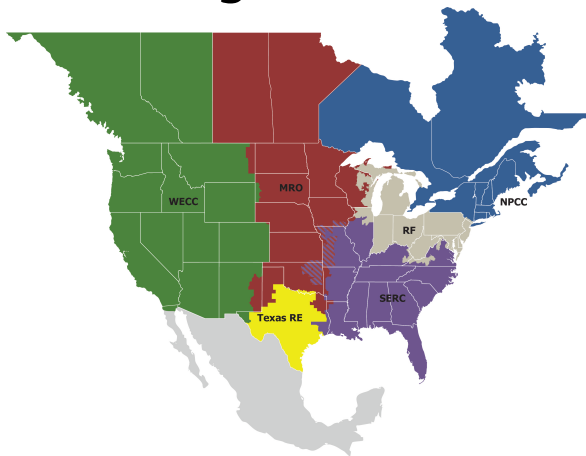
U.S. Electric Transmission Lines

Electric Transmission Lines

Power System   Long-Term Dynamics   Time-Sequenced Power Flows   Recap   Quick Results   Final Bits   References
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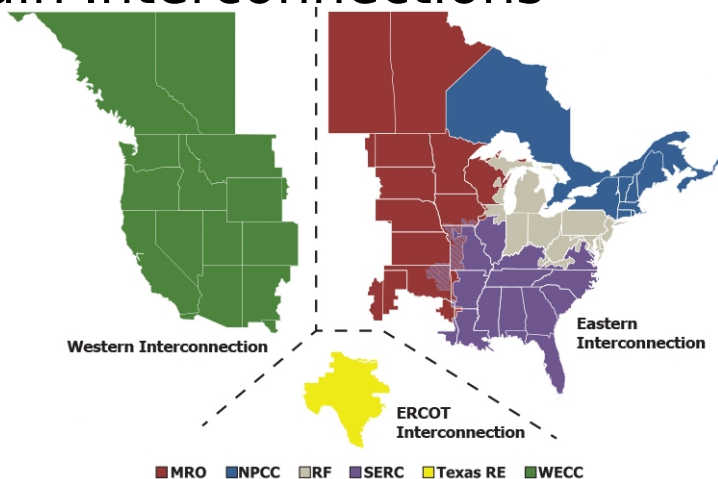
Operational Structure
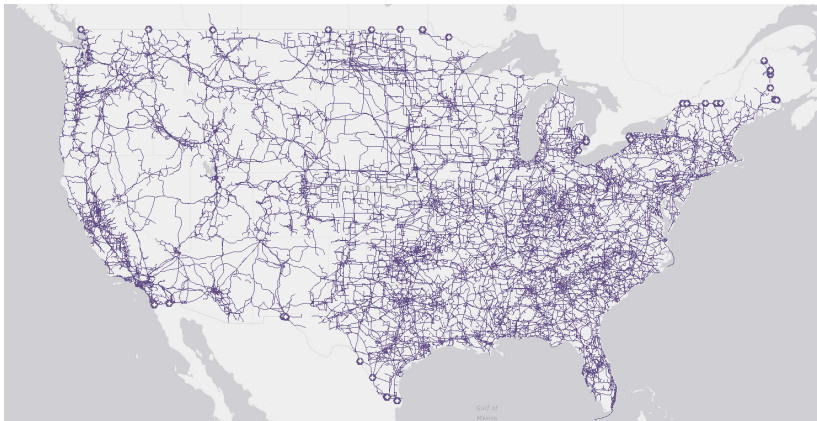
'People in Charge'

- ► **FERC** Federal Energy Regulatory Commission
  Part of the Department of Energy
- ► **NERC** North American Electric Reliability Corp.
  Aurthority granted by FERC
- ► **Balancing Authorities**
  Manage specific portions of the power
  system to balance supply and demand
  and maintain mandatory operating
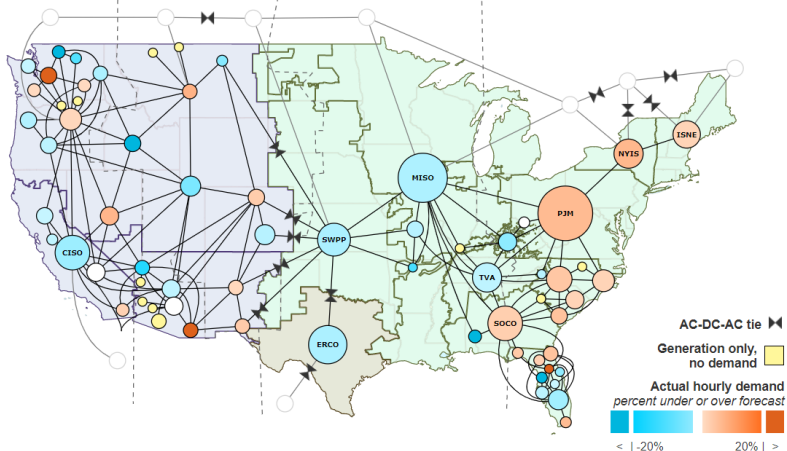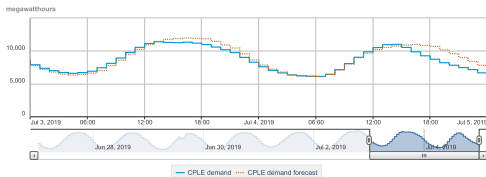 conditions set by FERC and NERC.

Power System Long-Term Dynamics Time-Sequenced Power Flows Recap Quick Results Final Bits References
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Operational Structure

Six NERC Regions

Main Interconnections

Western Interconnection

Eastern Interconnection

ERCOT Interconnection

■ MRO ■ NPCC ▢ RF ■ SERC ■ Texas RE ■ WECC

Balancing Authorities (BAs)

AC-DC-AC tie ►|◄

Generation only, no demand

Actual hourly demand
percent under or over forecast

< | -20%   20% | >

BA Action - Forcasting

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

Balancing authority forecast error 06/27/2019 – 07/04/2019, EDT
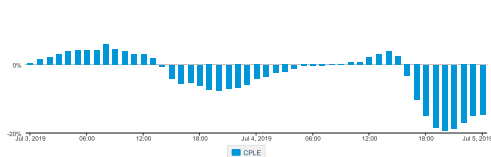
BA Action - Import & Export

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

Source: U.S. Energy Information Administration

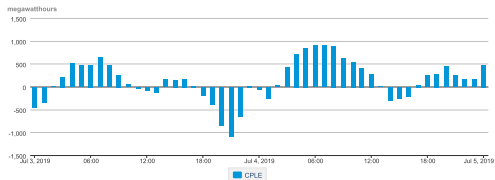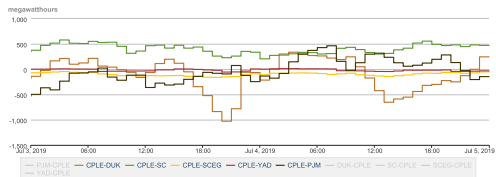Balancing authority electricity flow 06/27/2019 – 07/04/2019, EDT

Source: U.S. Energy Information Administration

BA Action - Interchange Error

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

Source: U.S. Energy Information Administration

Power System Long-Term Dynamics Time-Sequenced Power Flows Recap Quick Results Final Bits References
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Explanation of Wording
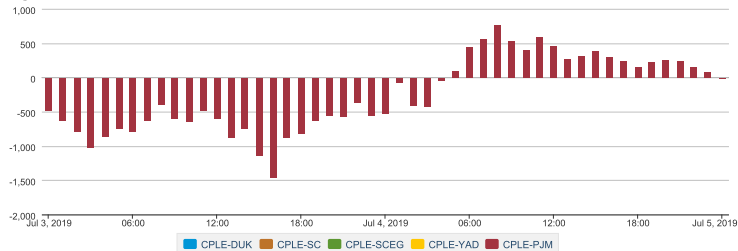
What is Long-Term?

Long-term describes the amount of time
required for events of interest to occur
and the simulation length to be executed.

In this case: 10 to 60 minutes

Explanation of Wording

What is Dynamic Simulation?

A computer's mathematical estimation of how a system will change over time.

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

Power System Long-Term Dynamics Time-Sequenced Power Flows Recap Quick Results Final Bits References
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Key Dynamic Concepts of Interest

Frequency, Accelerating power and Inertia.

$$\dot{\omega}_{sys} = \frac{1}{2H_{sys}} \left(\frac{P_{acc,sys}}{\omega_{sys}(t)} - D_{sys}\Delta\omega_{sys}(t) \right)$$

Direct link - electric demand always met. If there isn't enough generation, the kinetic energy stored as a moving inertia in a generator is converted to electric energy and the generator slows down.

Power System Long-Term Dynamics Time-Sequenced Power Flows Recap Quick Results Final Bits References
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Key Dynamic Concepts of Interest

Governors Defined:
Turbine speed governors adjust a
machines mechanical power to stop
frequency decline. Input is frequency
deviation and current operating set point.
Primary control.

Key Dynamic Concepts of Interest

Automatic Governor Control Defined
(AKA Load Frequency Control)
Adjusts generator nominal operating set
point to remove any inadvertent
interchange and restore system frequency
to 60 Hz. Secondary Control.

Key Dynamic Concepts of Interest

Multi Area Interactions
Areas import or export power to each
other.

Power System Long-Term Dynamics **Time-Sequenced Power Flows** Recap Quick Results Final Bits References
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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 power system.

Power flows are do not care about time.

Power System Long-Term Dynamics Time-Sequenced Power Flows Recap Quick Results Final Bits References
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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, . . .)

Power System   Long-Term Dynamics   Time-Sequenced Power Flows   Recap   Quick Results   Final Bits   References
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Transient Simulation Differences

Transient vs Long-Term Simulation

Time scale. Level of detail required.
Equations - transient used ODE to find
next steady state, LTD used ODE to find
next guess of input to power flow.

Power System Long-Term Dynamics Time-Sequenced Power Flows Recap Quick Results Final Bits References
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General Project Overview

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'.

Power System Long-Term Dynamics Time-Sequenced Power Flows Recap Quick Results Final Bits References
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General Project Overview

And why?

To study engineering problems involving:

- ► Long-term events (i.e. Wind Ramps)
- ► Multi-Area Power Interactions
    - ► Inadvertent Interchange
    - ► Turbine governor settings
    - ► Automatic Generation Control Settings
    - ► Governor and AGC interaction
- ► 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) produces valid output for small to medium size systems.

► Governor and AGC interactions can happen easily

► Deadbands and conditional logic can be used to limit governor and AGC conflicts

Continuing Work

- ► Experiments with AGC and turbine speed governor settings.
- ► Use of valve travel and system reliability as to measure validity of control regime.
- ► Expansion of software capabilities to handle full WECC.

Questions?

References I

[1]   P. M. Anderson and A. A. Fouad, *Power System Control and Stability*, Second Edition. Wiley-Interscience, 2003.

[2]   A. Aziz, A. Mto, and A. Stojsevski, "Automatic generation control of multigeneration power system," Journal of Power and Energy Engineering, 2014.

[3]   J. Carpentier, "'To be or not to be modern' that is the question for automatic generation control (point of view of a utility engineer)," International Journal of Electrical Power & Energy Systems, 1985.

[4]   F. P. deMello and R. Mills, "Automatic generation control part II - digital control techniques," IEEE PES Summer Meeting, 1972.

[5]   D. Fabozzi and T. Van Cutsem, "Simplified time-domain simulation of detailed long-term dynamic models," IEEE Xplore, 2009.

[6]   GE Energy, *Mechanics of running pslf dynamics*, 2015.

References II

[7]   General Electric International, Inc, *PSLF User's Manual*, 2016.

[8]   W. B. Gish, "Automatic generation control algorithm - general concepts and application to the watertown energy control center," Bureau of Reclamation Engineering and Research Center, 1980.

[9]   J. D. Glover, M. S. Sarma, and T. J. Overbye, *Power System Analysis & Design*, 5e. Cengage Learning, 2012.

[10]   M. Goossens, F. Mittelbach, and A. Samarin, *The LaTeX Companion*. Addison-Wesley, 1993.

[11]   E. Heredia, D. Dosterev, and M. Donnelly, "Wind hub reactive resource coordination and voltage control study by sequence power flow," IEEE, 2013.

References III

[12]   Y. G. Kim, H. Song, and B. Lee, "Governor-response power flow (grpf) based long-term voltage stability simulation," IEEE T&D Asia, 2009.

[13]   P. Kundur, *Power System Stability and Control*. McGraw-Hill, 1994.

[14]   Y. Mobarak, "Effects of the droop speed governor and automatic generation control agc on generator load sharing of power system," International Journal of Applied Power Engineering, 2015.

[15]   B. Rand. (2018), Agent-based modeling: What is agent-based modeling? Youtube, [Online]. Available: https://www.youtube.com/watch?v=FVmQbfsOkGc.

[16]   M. Stajcar, "Power system simulation using an adaptive modeling framework," Master's thesis, Montana Tech, 2016.

References IV

[17]   C. W. Taylor and R. L. Cresap, "Real-time power system simulation
         for automatic generation control," IEEE Transactions on Power
         Apparatus and Systems, 1976.

[18]   T. Van Cutsem and C. Vournas, *Voltage Stability of Electric Power
         Systems*, 1st ed. Springer US, 1998.