ECEN 615
Methods of Electric Power Systems Analysis

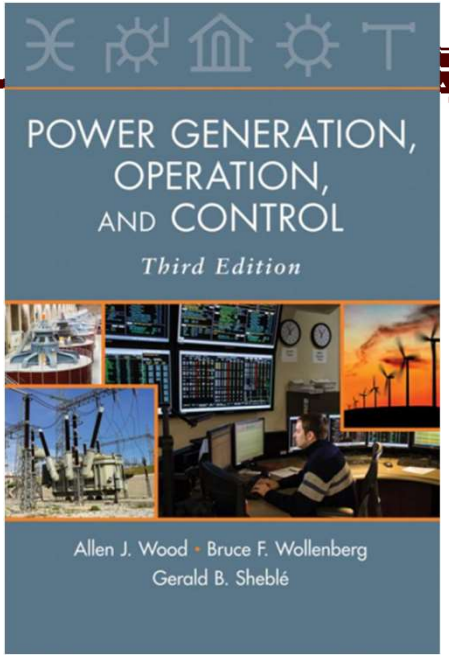
Lecture 1: Power Systems Overview

Prof. Tom Overbye
Dept. of Electrical and Computer Engineering
Texas A&M University
overbye@tamu.edu

Course Mechanics

- In Fall 2022 ECEN 615 is offered both live on campus in ETB 1003 on Tuesdays and Thursdays from 8 to 9:15 am (central) and via distance learning (DE)
  - The recorded lectures are available to both on campus and DE students
  - All students are welcome to attend the live lectures and on campus students should
- The course has a public website as well as a private Canvas website
  - We'll post all material on Canvas; all should be able to login to Canvas at canvas.tamu.edu (also from lms.tamu.edu)
  - Slides will be available on Canvas before each lecture, with often updated slides posted after the lecture
  - Much of the material will be on the public website, included the ppts of the lectures, but not the recordings

Syllabus Material



- The syllabus is posted in several locations
- The public website is
  - overbye.engr.tamu.edu/ecen-615-fall-2022/
- Assumed background is an undergrad power class
- The course will have homework and probably a project, as well as two in class exams
  - The final grade is 35% for the first exam, 35% for the second exam, and 30% for the homework and project
- The almost required book is A. J. Wood, B. F.Wollenberg, G. B. Sheble, *Power Generation, Operation and Control,* Third Edition, Wiley, 2013, ISBN-13: 978-0471790556

About Me: Professional

- Received BSEE, MSEE, and Ph.D. from UW-Madison
- Worked for eight years as engineer for Madison Gas & Electric
- Was at UIUC from 1991 to 2016, doing teaching and doing research in the area of electric power systems
- Joined TAMU in January 2017; Taught many power systems classes over last 29 years
- Developed commercial power system analysis package, known now as PowerWorld Simulator. This package has been sold to about 1000 different corporate entities worldwide
- DOE investigator for 8/14/2003 blackout
- Member US National Academy of Engineering

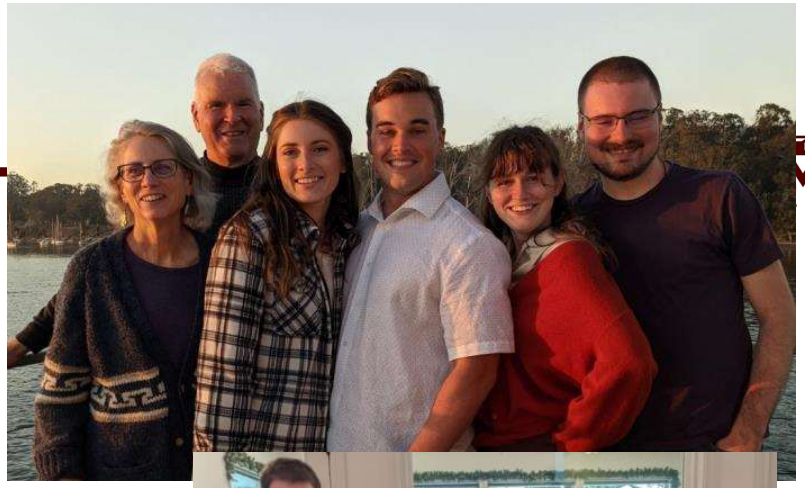
About Me: TAMU Research Group, Summer 2022

TAMU Energy and Power Group (EPG) Spring 2022 Dinner

All 615 students are invited to our fall event, which will be at Prof. Davis's house on Saturday October 1 (more details will be given soon)

Electric Grid Control Room at CIR

About Me: Nonprofessional



- Married to Jo; and have three children: Tim, Hannah and Amanda
- We homeschooled our kids with Tim now a PhD student at TAMU, Hannah is doing a PhD at UCSB in communications (and recently got married) and Amanda just graduated from Belmont in environmental sciences
- Jo is a counselor (LPC), we attend Grace Bible Church in College Station and teach 4th graders class (Creekside)
- I am the faculty advisor for Christian Engineering Leaders; I also like swimming, watching football (Aggies and Packers!)

About TA Sanjana Kunkolienkar

- Second year graduate student at TAMU
  - B.Tech. (Electrical Engineering, University of Mumbai (India))
- Worked at Siemens, India
- Research Interests
  - Everything Power Systems!
- Advisor: Prof. Tom Overbye
- Hobbies & Interests: Reading, Writing, Trekking and Painting
- Logistics Chair, Texas Power and Energy Conference 2023 (TPEC 2023)

(contact me for volunteer opportunities or if you want to know more about the conference!)

Austin, Texas

Some of my paintings

Texas Power and Energy Conference (TPEC)

- Starting in 2017 we have been hosting the Texas Power and Energy Conference on campus in either February or March
- TPEC 2022 was held Feb 28 to March 1 at the TAMU Memorial Student Center, with many students presenting papers
  - Technically co-sponsored with IEEE so papers appear in IEEE Xplore
  - Student run so there are LOTs of volunteer activities; tpec.engr.tamu.eud

Announcements

- Start reading Chapters 1 to 3 from the book (mostly background material)
- We'll be using PowerWorld Simulator fairly extensively in this class, both the educational and professional versions
- For now if you don't have a version, just download the free 42 bus educational versions of PowerWorld Simulator at

  https://www.powerworld.com/gloveroverbyesarma

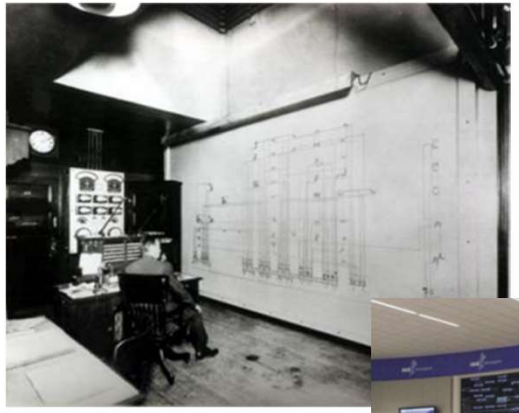
(be sure to get version 22; we might transition to version 23 if it comes out during the semester)

Course Topics

- Introduction to Power Systems
- Overview of Power System Modeling and Operation
- Power Flow
- Sparse Matrices in Power System Analysis
- Sensitivity Analysis and Equivalents
- Power System Data Analytics and Visualization
- Optimal Power Flow and Power Markets
- Power System State Estimation
- High Impact, Low Frequency Events

ECEN 615 Motivation: A Vision for a Long-Term Sustainable Electric Future

- In 2000 the US National Academy of Engineering (NAE) named Electrification (the vast networks of electricity that power the developed world) as the top engineering technology of the 20th century
  - Beating automobiles (2), airplanes (3), water (4), electronics (5)
  - Electricity has changed the world!
- For the 21th century the winner could be "Development of a sustainable and resilient electric infrastructure for the entire world"

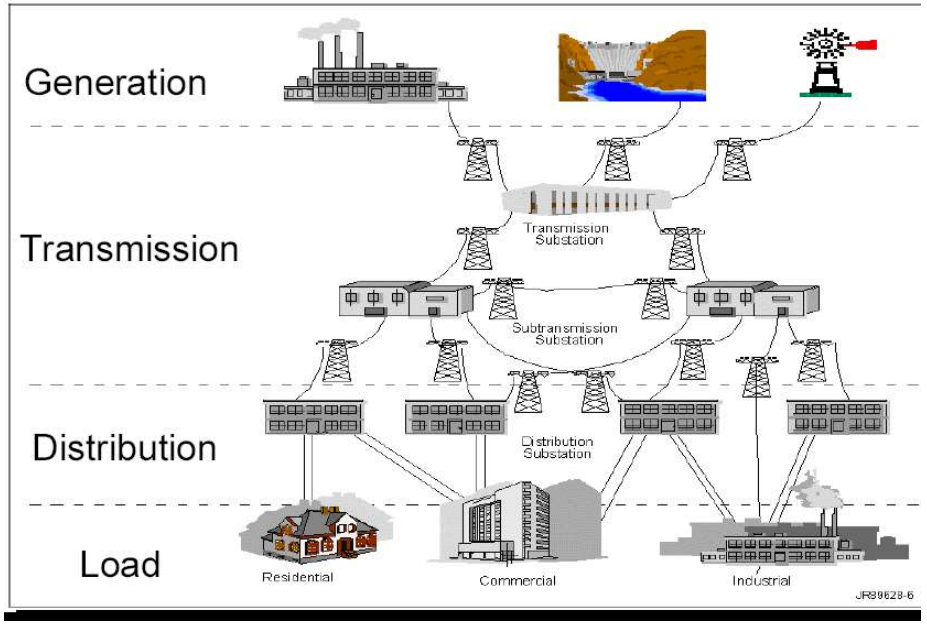


Power System Examples

- Electric utility: can range from quite small, such as an island, to one covering half the continent
  - there are four major interconnected ac power systems in North American, each operating at 60 Hz ac; 50 Hz is used in some other countries.
- Microgrids can power smaller areas (like a campus) and can be optionally connected to the main grid
- Airplanes and Spaceships: reduction in weight is primary consideration; frequency is 400 Hz.
- Ships and submarines
- Automobiles: dc 12 V standard; 360-376 V for electric
- Battery operated portable systems

Electric Grid Overview

- Generation – source of electric energy
  - Coal had provided over half of the U.S. electric energy, but now natural gas leads, with renewable sources rapidly growing
- Load – consumes electric energy
  - Consumers are in complete control of the switch; utilities must supply enough power to meet load
- Transmission and Distribution – the wires that carry the power from generation to load
  - Operating at voltages up to 765 kV (kilovolt), with 500 kV, 345 kV, 230 kV 161 kV and 138 kV common



Electric Grid Time Frames

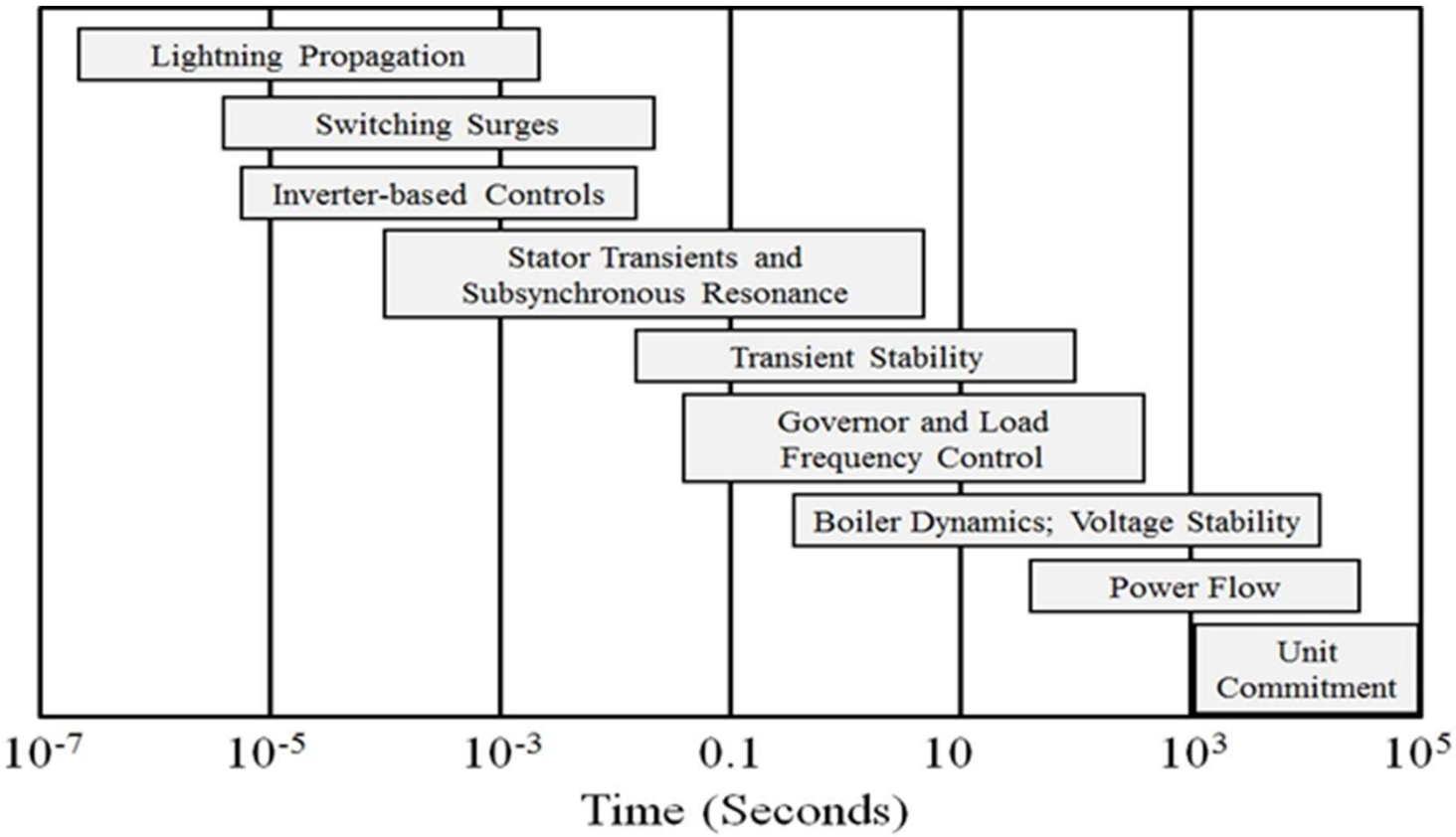


Image: Sauer, P.W., M. A. Pai, Power System Dynamics and Stability, Stripes Publishing, 2007

Power and Energy

- Power is the instantaneous transfer of energy; expressed in watts (W), kW, MW, GW
  - US installed generation capacity is about 1000 GW
- Energy is the integration of power over time; expressed in units of joules (J = 1 W-sec), kWh (3.6×10^6 J), or btu (1055 J; 1 MBtu=0.292 MWh)
- U.S. electric energy consumption is about 4100 billion kWh (about 12,500 kWh per person; 1.4 kW continuous per person on average)

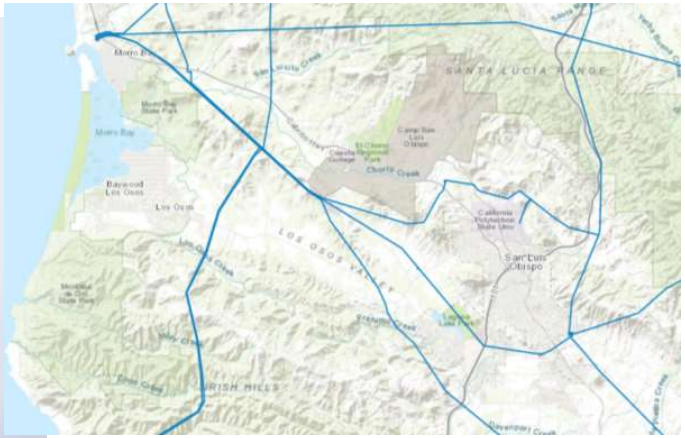
AC System Analysis

- The power grid is an ac system, operating at close to 60 Hz in North America, 50 Hz in many other places
- Constant frequency ac systems are analyzed using phasor analysis, which expresses a time varying value, such as a voltage or current, as a magnitude and phase angle
  - $v(t) = V_{max}\cos(\omega t + \theta_v) \rightarrow V_{rms}\angle \theta_v$
  - Phase angle is always with respect to an arbitrary reference angle
- In 615 we'll almost always be talking about ac systems and looking at the average power over a cycle

Three-Phase Systems

- Essentially all large-scale electric grids are three-phase
  - Three wires, with the same voltage magnitude and a phase shift of 120 degrees
- Usually the high voltage electric grid is “balanced,”
  - This means that it can be very well modeled as an equivalent single-phase system
  - The three-phase lines are often shown with a single line, what is known as a oneline


230 kV dual circuit




138 kV

Synchronous Electric Grids

- Much of the electricity in the developed world is supplied by large-scale, 60 or 50 Hz synchronous electric grids
  - Such grids can provide improved reliability, larger electricity markets and often economics of scale
  - However, they add planning complexities
  - Power can be transferred between synchronous grids by first converting it to dc, with HVDC lines one example
- Islands, and other parts of the world are supplied by smaller electric grids

Large-Scale Electric Grid Interconnections

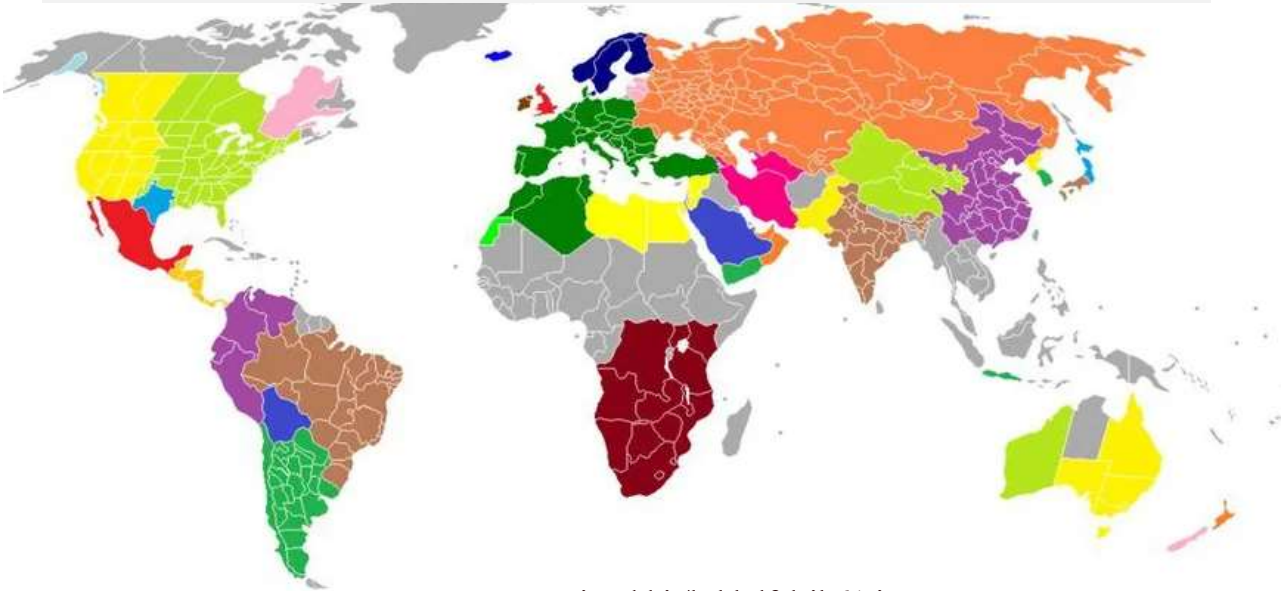
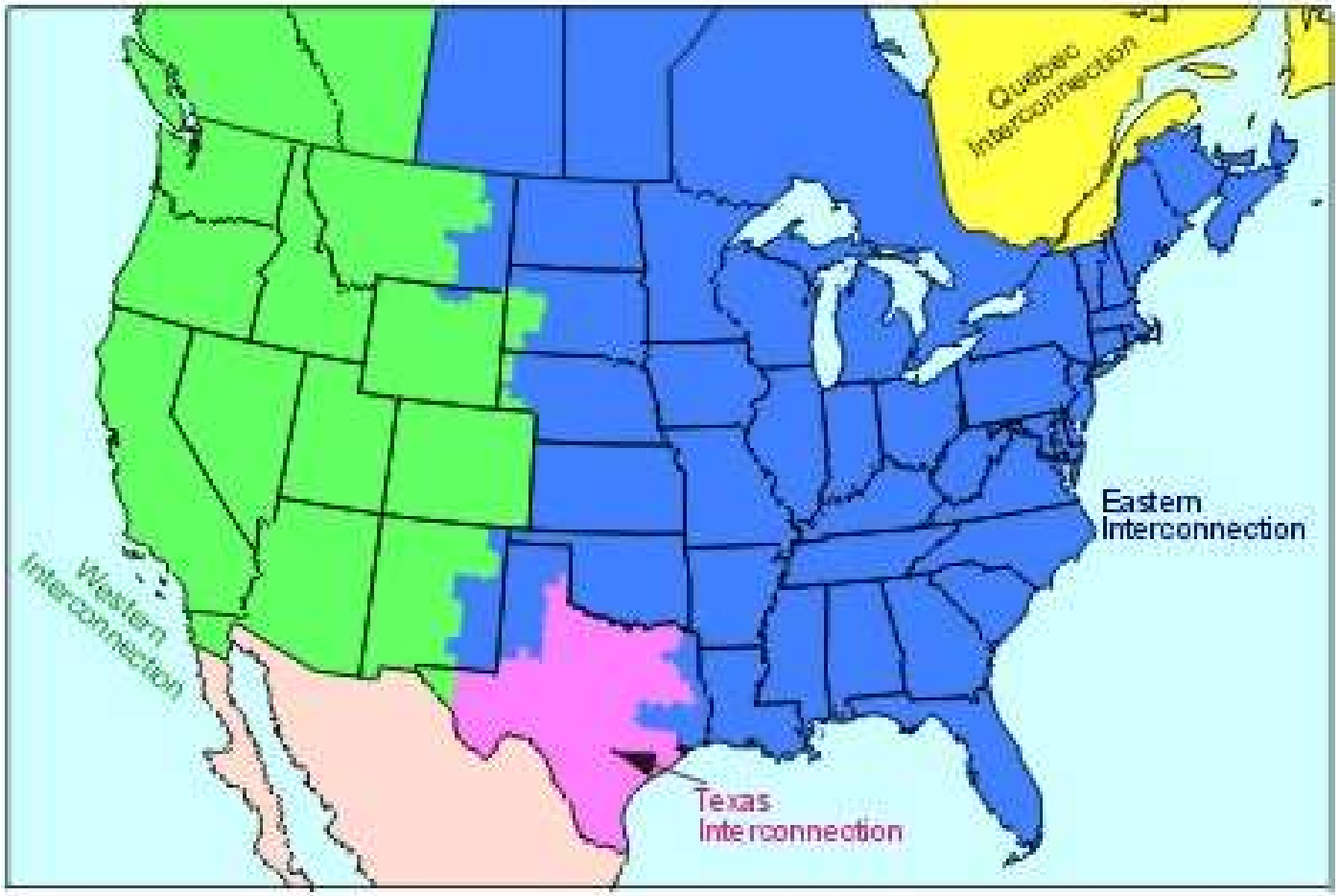


Image Source: i.redd.it/krkhdfslrjh61.jpg

North America Interconnections



All Three US Grids Are 60 Hz, But Are Not Usually At the Same Value

- Images show the frequency during the 2022 Super Bowl (2/13/22)

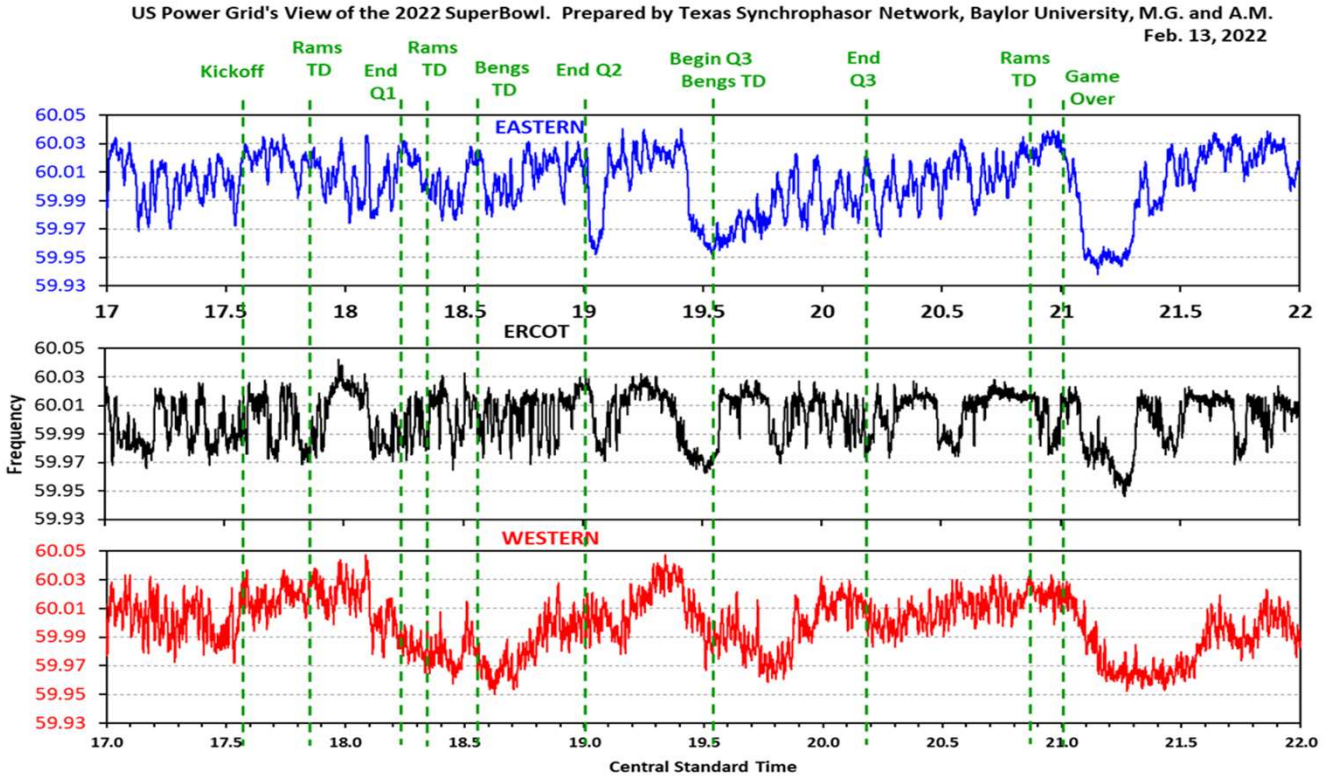
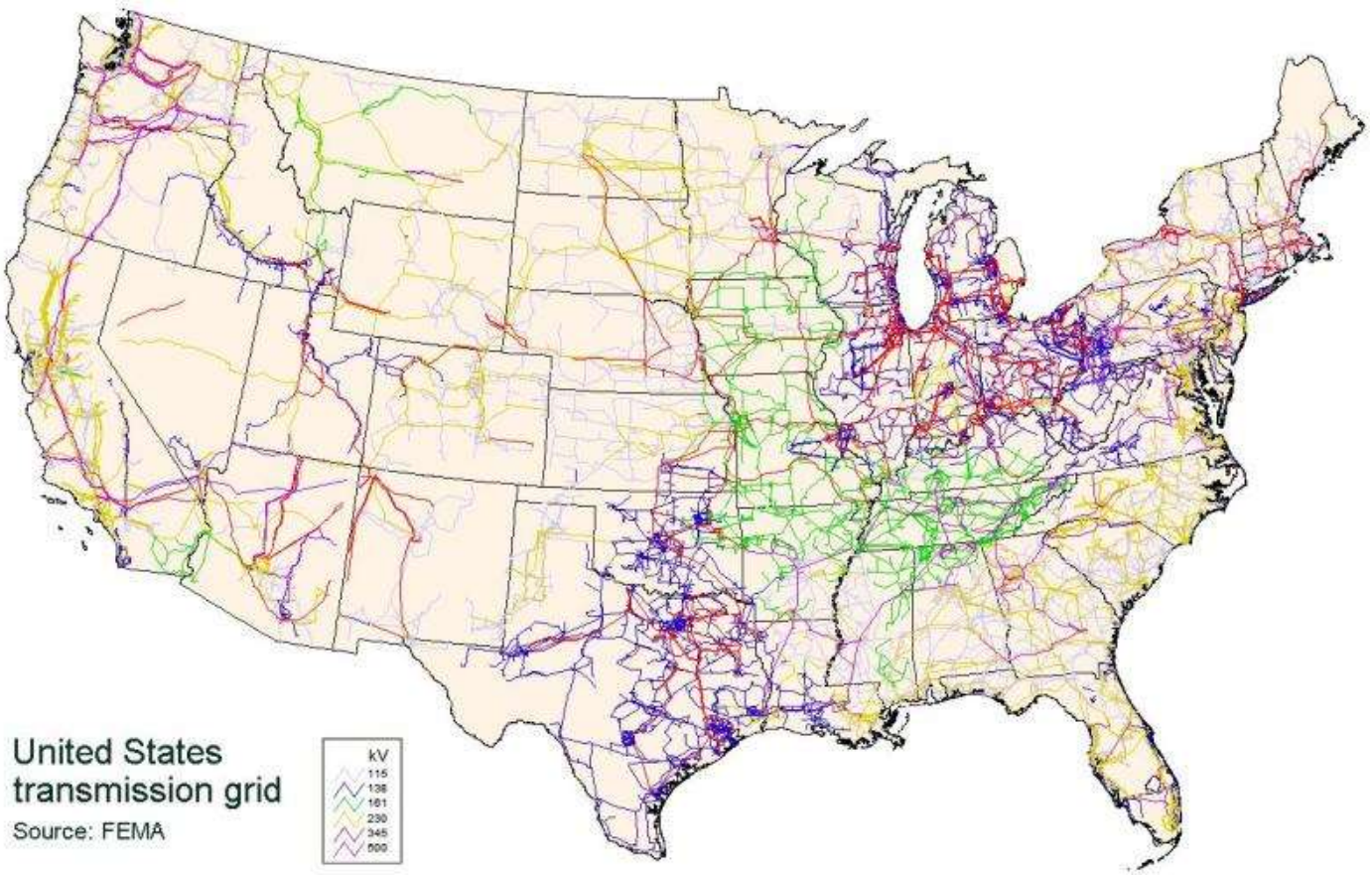


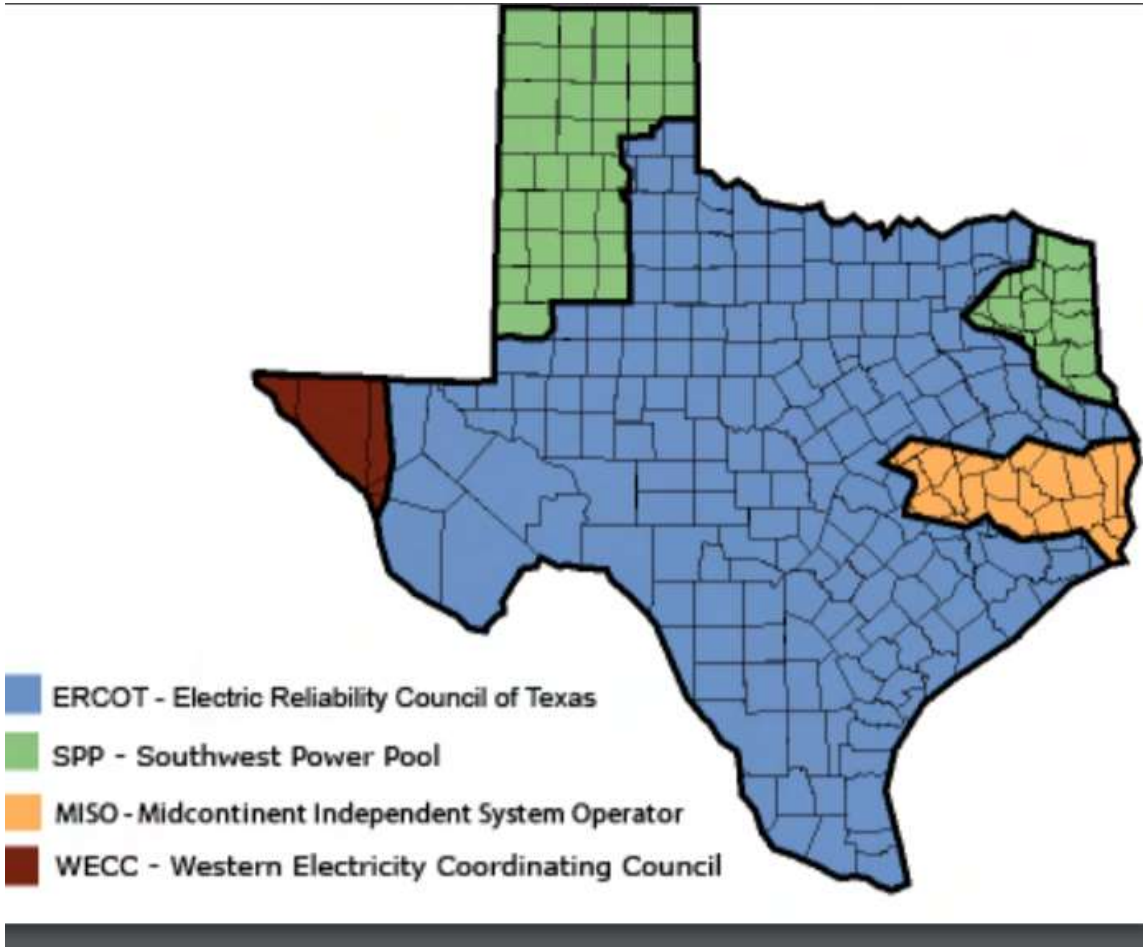
Image from Prof. Mack Grady of Baylor University

Continental US Transmission Grid



The Continental US Grid is interconnected with Canada and parts of Mexico

Electric Interconnections in Texas



El Paso is in the Western Interconnect (WECC) and parts of North and East Texas are in the Eastern Interconnect (EI) (with the boundaries in the image just approximate)

Lubbock Power and Light customers joined ERCOT in May 2021

Source: www.puc.texas.gov/industry/maps/maps/ERCOT.pdf