ECEN 667
Power System Stability

Lecture 1: Overview

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TEXAS A&M UNIVERSITY

Welcome and Course Mechanics

- In Fall 2023 ECEN 667 is offered both live on campus in ETB 1003 on Tuesdays and Thursdays from 8 to 9:15 a.m. (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, including Canvas, Howdy and on the public website
- The public website is
  - overbye.engr.tamu.edu/course-2/ecen-667-fall-2023/
    - 2021 class is at overbye.engr.tamu.edu/course-2/ecen667fa2021/
- Canvas access (TAMU students only) is lms.tamu.edu
- The assumed background is some knowledge of power system analysis (TAMU ECEN 460 or 615), or concurrent enrollment in a course such as 615
- Course staff is Prof. Tom Overbye and TA Sanjana Kunkolienkar
  - Email is the best contact: overbye@tamu.edu, sanjanakunkolienkar@tamu.edu

Syllabus Material, cont.

- The course will have homework, maybe a project, and two in class exams
  - Final grade is based 35% from the first exam, 35% from the second, and 30% from the homework (and perhaps the project)
  - Exam dates are Tuesday October 3 and Thursday November 30.
  - All grading in the course is based on a percentage, with final grades determined based on this percentage. If your final average falls within the below ranges you are guaranteed to receive at least the letter grad indicated: A: 90-100; B: 80-89; C: 70-79; D: 60-69; F: 59 or lower
- Last day of class for 667 is Thursday November 30

Course Text

- The course text is P. W. Sauer, M. A. Pai, J. H. Chow, *Power System Dynamics & Stability*, John Wiley and Sons, 2018 [ISBN-13: 978-1119355779]) (the first edition, from 1997 and updated in 2006, is also fine)
  - The 2018 edition is quite similar to the 2006 version, except with two new chapters, one on synchronized phasor measurements (which we'll cover) and one on the Power System Toolbox (which we won't since we'll be using the commercial PowerWorld Simulator and PowerWorld DS tools)

Course Slides

- Much of the course material will be presented via PowerPoint slides
- Prior to each lecture the draft slides will be available in Canvas
- After each lecture an updated version of the slides will be posted in Canvas
  - Usually modified based on the number of slides we actually covered
- Student questions are greatly encouraged!

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; now Section 6 Vice Chair

About Me: TAMU Research Group, Summer 2023

TAMU Energy and Power Group (EPG)
Spring 2023 Dinner

All 667 students are invited to our fall event, which will be at Prof. Begovic's house on Saturday September 9 (signup details will be given soon)

Electric Grid Control Room at CIR

About Me: Nonprofessional

- Married to Jo; and have three children: Tim, Hannah (now with Will) 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 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

- Third 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
- Co-director, Texas Power and Energy Conference 2024 (TPEC 2024)
  (email Sanjana for TPEC volunteer opportunities!)

Austin, Texas

Power Hour
(email Sanjana to get added to the MS Teams group!)

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 2023 was held Feb 13-14 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.edu

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 23)

On campus students consider signing up for the Energy and Power Group seminar on Fridays at 1130am in ETB 1020 (ECEN 681, Section 604)

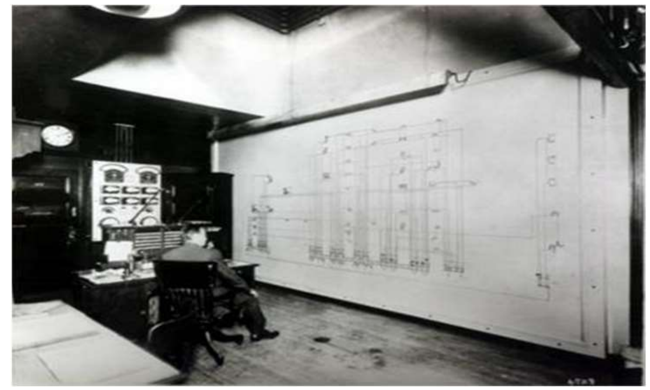
Course Topics

1. Introduction to power system structures and simulation
2. Electromagnetic transients ←
3. Synchronous machine modeling
4. Excitation and governor modeling
5. Single machines
6. Time-scales and reduced-order models
7. Interconnected multi-machine models
8. Transient stability
9. Linearization and the control problem
10. Signal analysis
11. Power System Stabilizer (PSS) design
12. Applications of Synchrophasor Measurements

This is covered more fully in ECEN 616, which should be taught next year

ECEN 667 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), and 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"

Our Energy Future Could be Bright!

- My professional goal is to help in the development of a sustainable and resilient electric infrastructure for the entire world.
- Electric grids are in a time of rapid transition, with lots of positive developments and lots opportunities for people entering the field
- I think our electric energy future could be quite bright! But there are lots of challenges with this transition, including maintaining human situational awareness, particularly during times of stress.
- ECEN 667 material will be key!

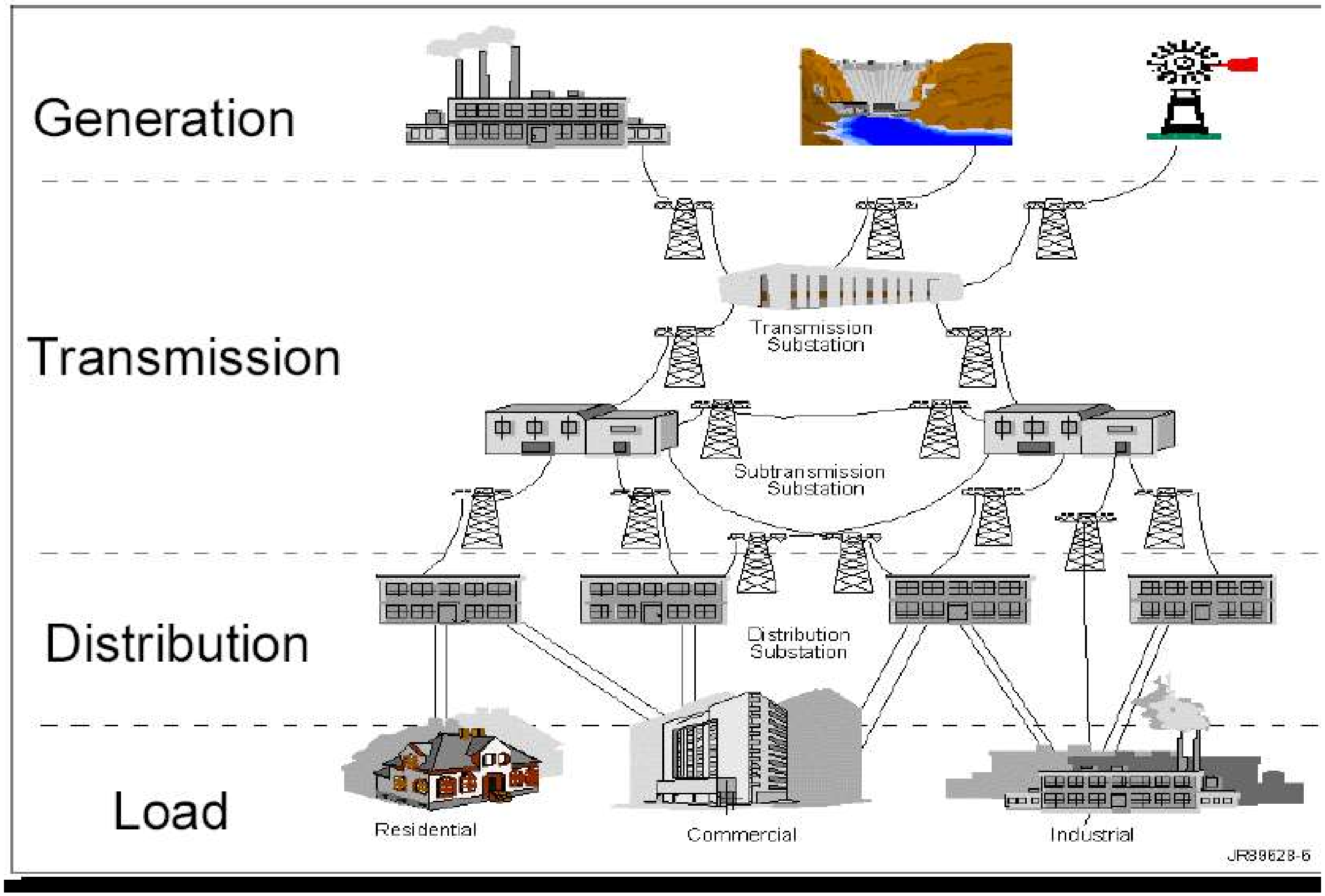
Power System Examples

- 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 and 230 kV common

Major Power Grid Components



The distribution system is the source of most outages, but these are almost always small-scale events

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
- Much of what we do in 667 is based on this near constant frequency assumption, with Chapter 2 an exception

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

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

Electric Frequencies and Residential Voltages Worldwide

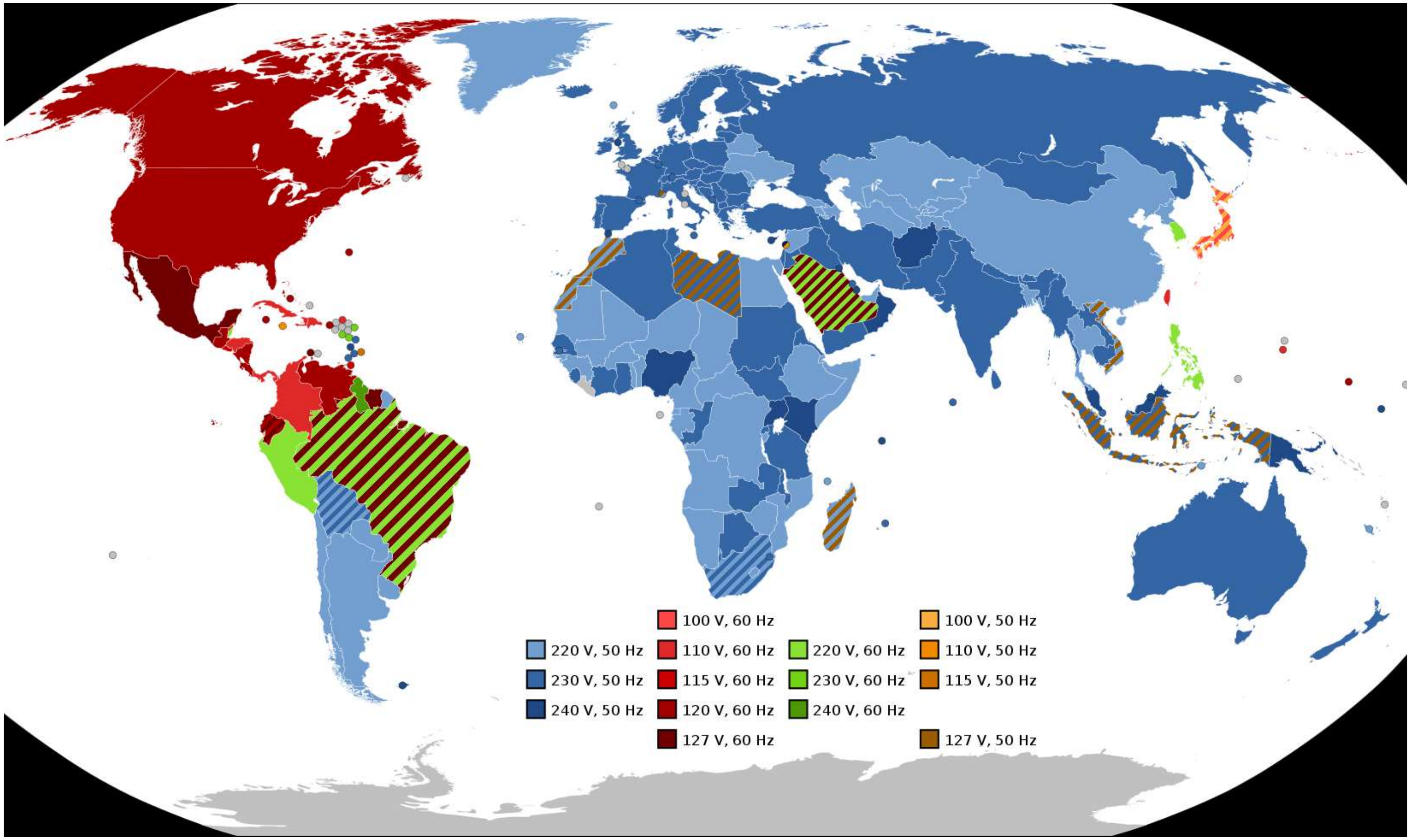
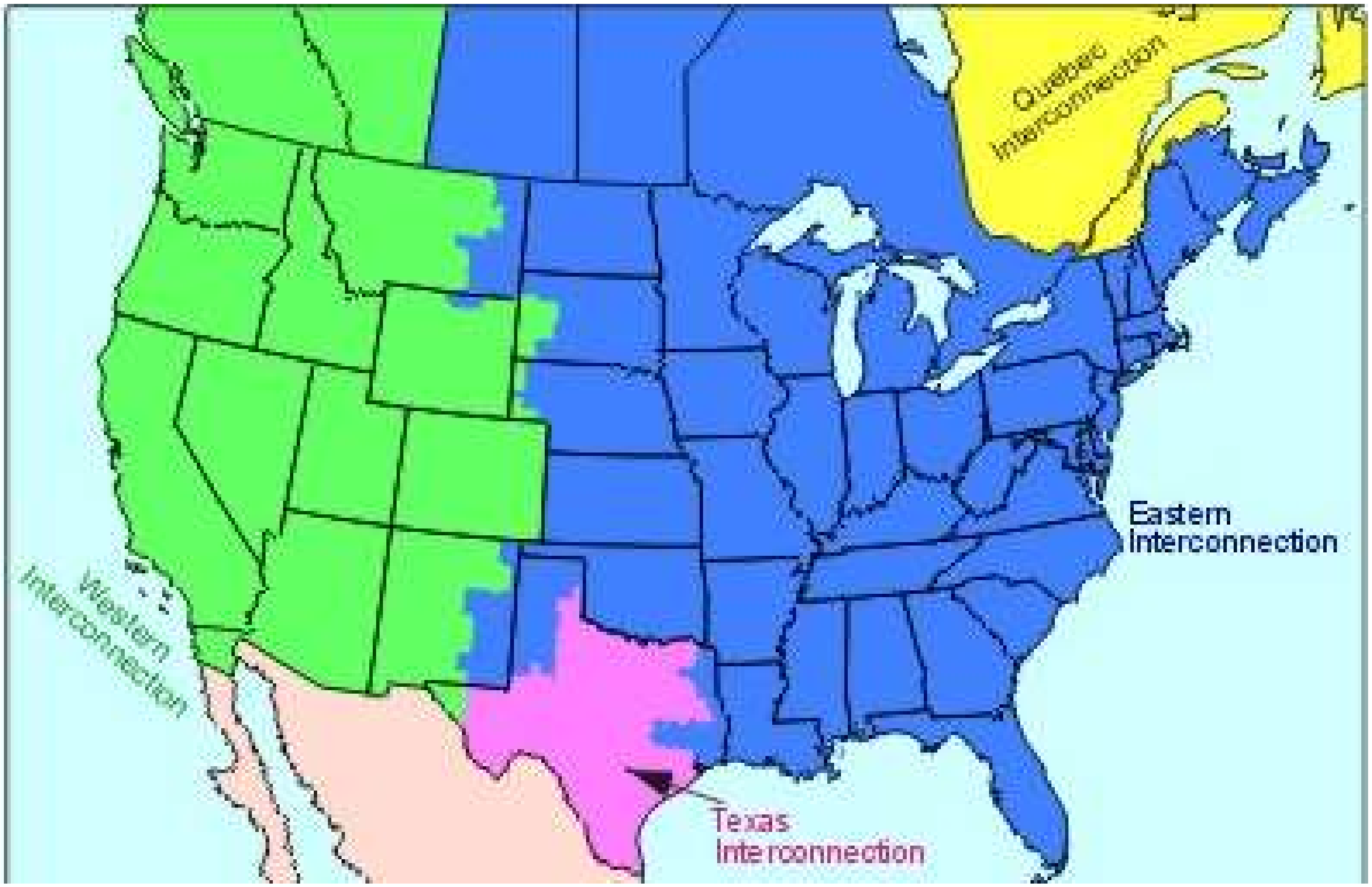


Image Source: en.wikipedia.org/wiki/Mains_electricity_by_country#/media/File:World_Map_of_Mains_Voltages_and_Frequencies,_Detailed.svg

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

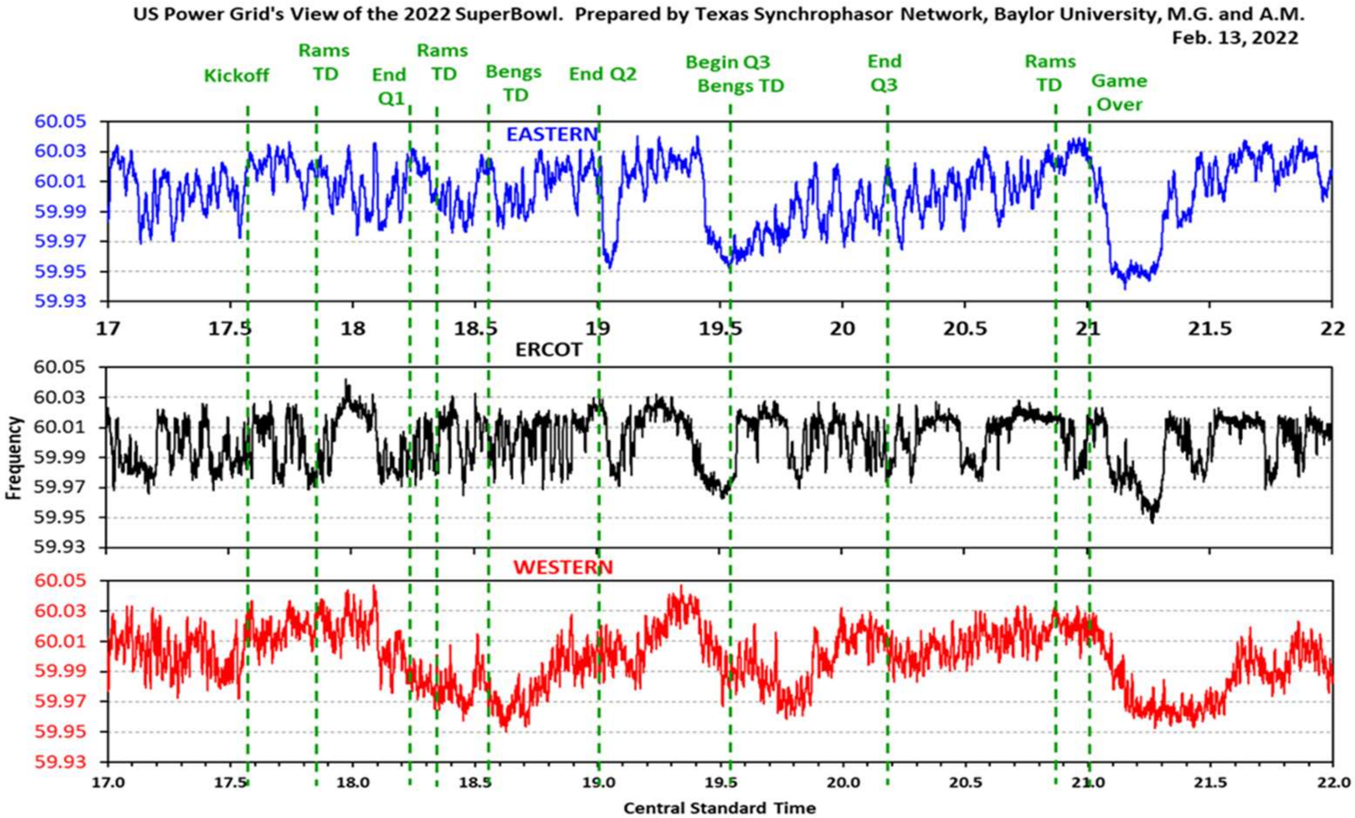
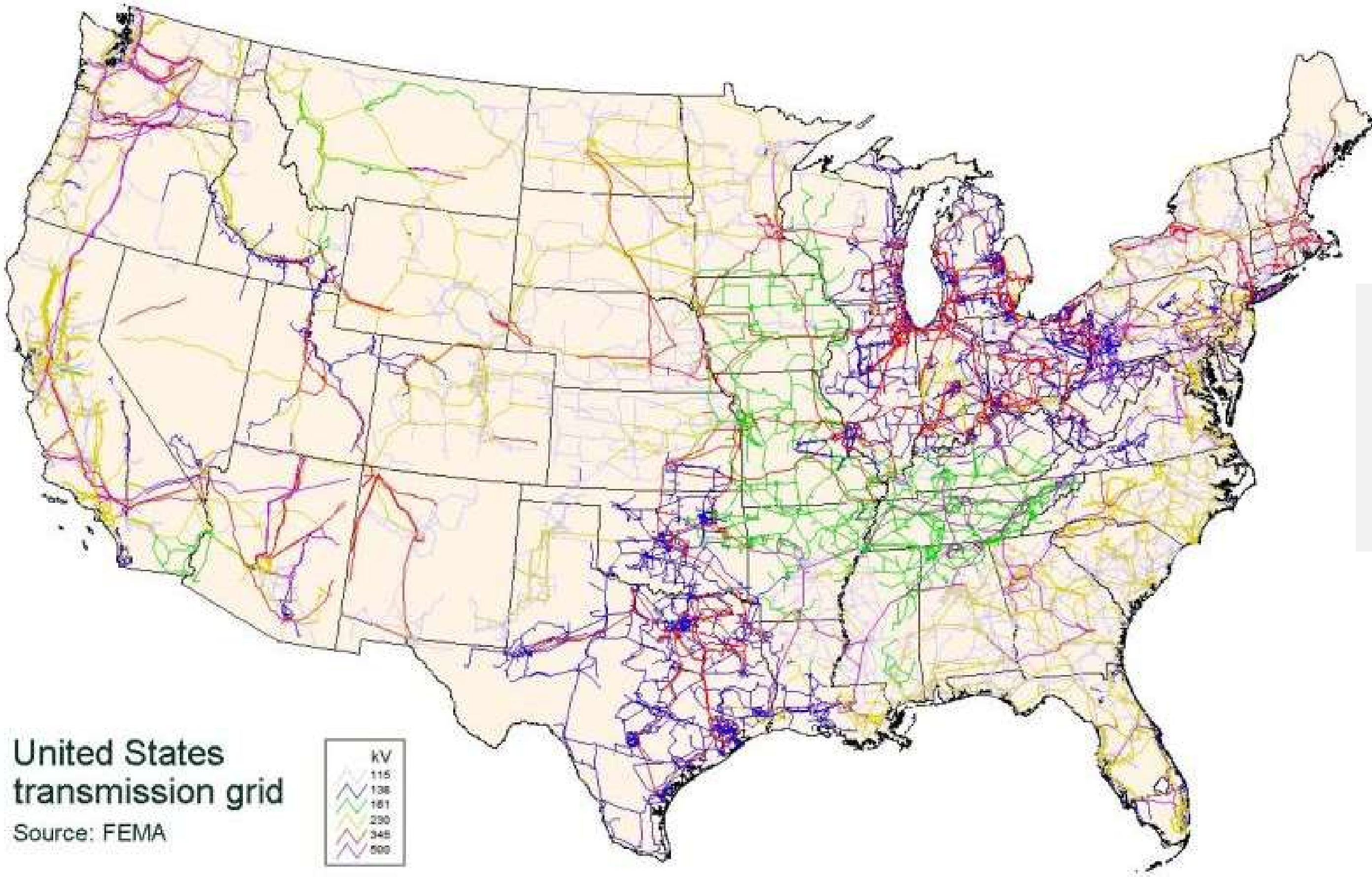


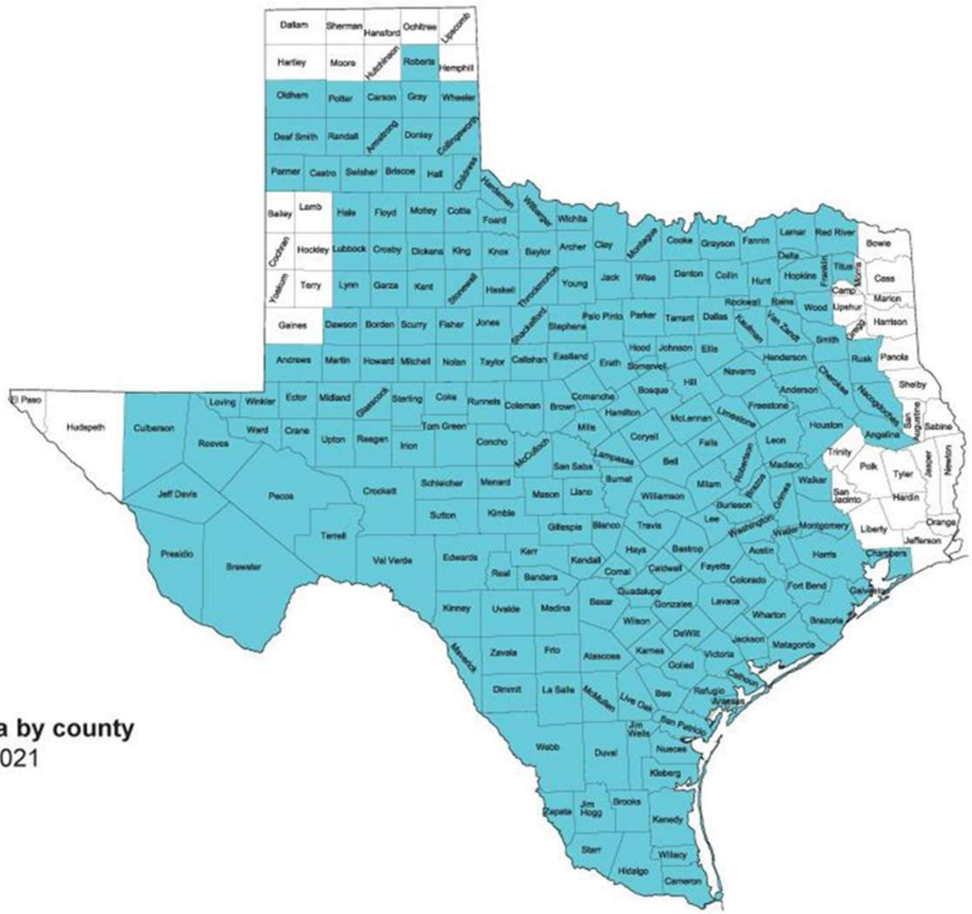
Image from Prof. Mack Grady of Baylor University

Contiguous US Transmission Grid



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

Most of Texas Has Its Own Grid: The Electric Reliability Council of Texas (ERCOT)

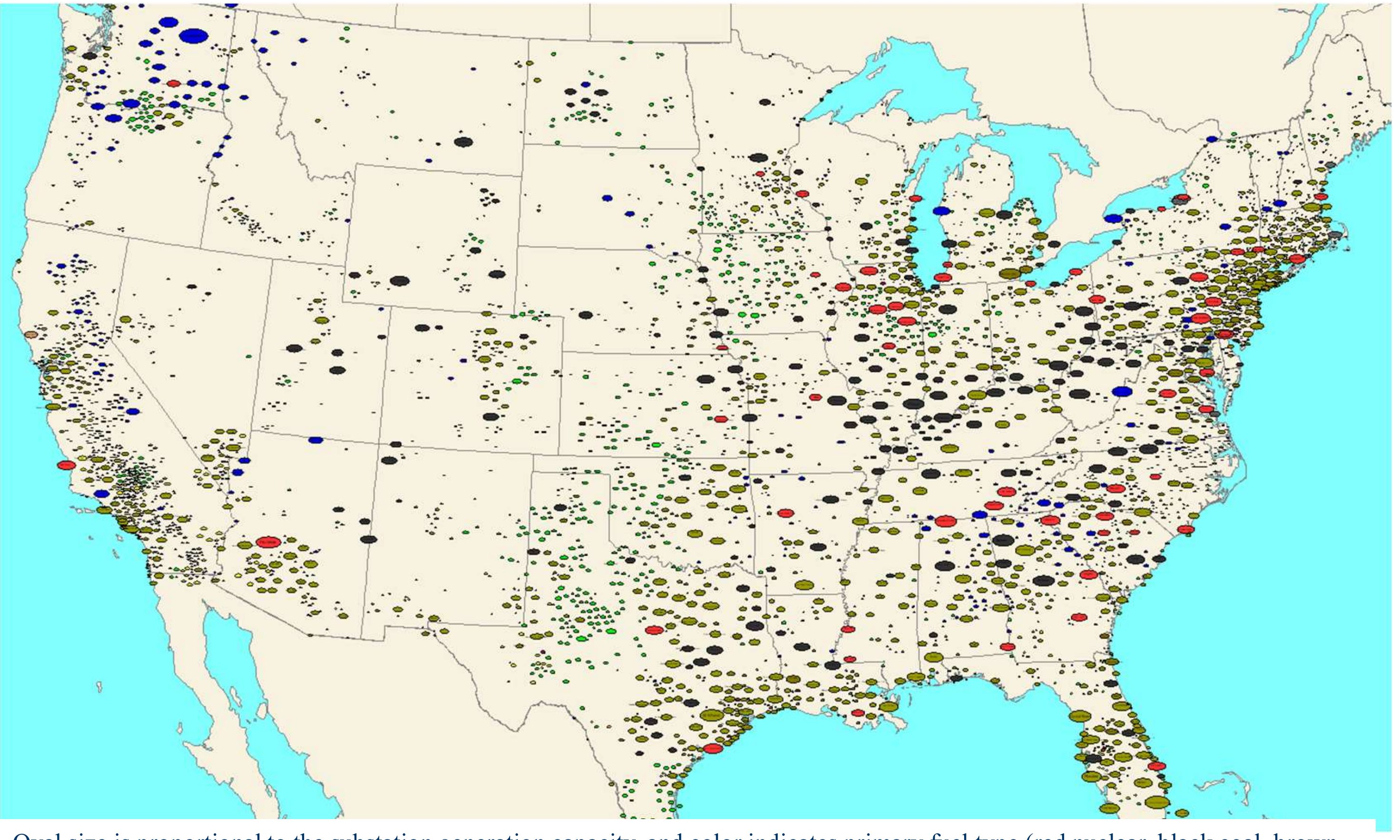


ERCOT area by county
as of June 2021

El Paso is in the Western Interconnect (WECC) and parts of North and East Texas are in the Eastern Interconnect (EI) (with the boundaries not always by county)

Source: www.ercot.com/news/mediakit/maps

North America Electric Grid Model Generation



Oval size is proportional to the substation generation capacity, and color indicates primary fuel type (red nuclear, black coal, brown natural gas, blue hydro, green wind, yellow solar). Image shows public data from EIA Form 860;

Power System Time Frames

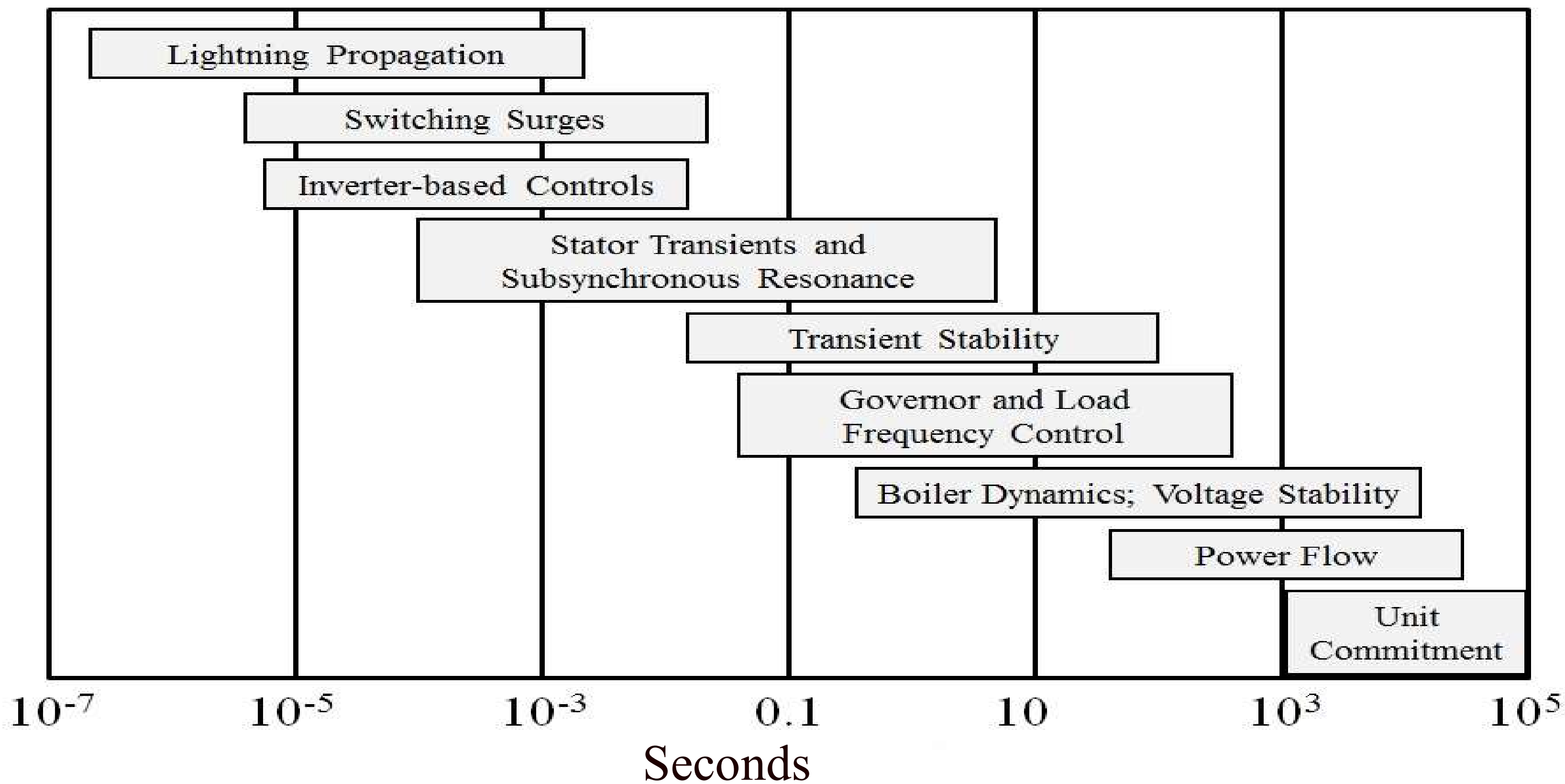


Image source: P.W. Sauer, M.A. Pai, Power System Dynamics and Stability, 2006, Fig 1.2, modified

Course Coverage

- Course is focused on the analysis of the dynamics and stability of high voltage power systems
  - Some consideration of general solution methods, some consideration of power system component modeling in different time frames, and some consideration of using tools to solve example larger-scale power system problems
- Course seeks to strike a balance between the theoretical and the applied
- "In theory there is no difference between theory and practice. In practice there is." -- Yogi Berra (maybe he said this, or perhaps anonymous)

Modeling Cautions!

- "All models are wrong, but some are useful," George Box, *Empirical Model-Building and Response Surfaces*, (1987, p. 424)
  - Models are an approximation to reality, not reality, so they always have some degree of approximation
  - Box went on to say that the practical question is how wrong to they have to be to not be useful
- A good part of engineering is deciding what is the appropriate level of modeling, and knowing under what conditions the model will fail
- Always keep in mind what problem you are trying to solve!

Putting ECEN 667 in Context

- Research can be broken into two broad categories
  - Those with problems looking for solutions
  - Those with solutions looking for problems
- Research is needed in both areas!
- Power systems is more in the first category: we've got problems associated with designing and operating large-scale electric grids, and often look to other domains for solutions
  - More a focus on domain knowledge; we know the domain and then have a working knowledge of many solution methods
  - This is the approach used in ECEN 667

PowerWorld Simulator

- Class will make extensive use of PowerWorld Simulator and DS. If you do not have a copy of version 23, the free 42 bus student versions are available for download at

  http://www.powerworld.com/gloveroverbyesarma

- Start getting familiar with this package, particularly the power flow basics. Stability aspects will be covered in class
- Free training material is available at

http://www.powerworld.com/training/online-training

Slow versus Fast Dynamics

- Key analysis question in setting up and solving models is to determine the time frame of interest
- Values that change slowing (relative to the time frame of interest) can be assumed as constant
  - Power flow example is the load real and reactive values are assumed constant (sometimes voltage dependence is included)
- Values that change quickly (relative to the time frame of interest) can be assumed to be algebraic
  - A generator's terminal voltage in power flow is an algebraic constraint, but not in transient stability
  - In power flow and transient stability the network power balance equations are assumed algebraic