ECEN 667
Power System Stability

Lecture 1: Overview and Numeric Solution of Differential Equations

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TEXAS A&M UNIVERSITY

Welcome and Course Mechanics

- This semester ECEN 667 is being offered both as a regular course on campus (in ETB 1037 on Tuesdays and Thursdays from 8 to 9:15am) and via distance learning (DE)
  - The lectures are automatically recorded and made available to the DE students
- The course has a public website and as well as a Canvas website
  - We'll post all material for the enrolled students on Canvas, including (I believe) the recorded lectures
  - The public site is to provide access for non-TAMU people to the slides and some other material

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/ecen667fa2021/
    - 2019 class is at overbye.engr.tamu.edu/course/ecen667fa2019/
- 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 Wei Trinh
  - Email is the best contact: overbye@tamu.edu, weit1@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 Thursdays October 14 and December 2
  - 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 Tuesday December 7

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. all from University of Wisconsin at Madison (83, 88, 91)
- Worked for eight years as engineer for an electric utility (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 30 years
- Developed commercial power system analysis package, known now as PowerWorld Simulator. This package has been sold to about 600 different corporate entities worldwide
- DOE investigator for 8/14/2003 blackout
- Member US National Academy of Engineering

About Me: TAMU Research Group Spring 2019, Summer 2021

About Me: Nonprofessional

- Married to Jo
- Have three children: Tim, Hannah and Amanda
- We homeschooled our kids with Tim now a PhD student at TAMU, Hannah starting grad school at UCSB, and Amanda a senior at Belmont in environmental sciences
- Jo works as a counselor at A&M Christian Counseling, we attend Grace Bible Church in College Station (and teach the 3rd graders); I am the faculty advisor for Christian Engineering Leaders; I also like swimming, biking and watching football (Aggies and Packers!)

A Few More Photos, Non-Professional

About TA Wei Trinh

- Fifth year PhD student
  - BS (Physics, University of Maryland, Baltimore County)
  - BS (Mathematics, University of Maryland, Baltimore County)
- PhD Research Area
  - Power Systems Dynamics
  - Modal Analysis Techniques
- Advisor: Prof. Tom Overbye
- Hobbies & Interests: Photography, cooking, video games
- Former Co-Director, Texas Power and Energy Conference (TPEC)

Sample of photos I’ve taken

TPEC 2020 in College Station, Texas

TAMU ECE Energy and Power Group Picnic: September 25, 2021

This picture is from two years back. You are welcome to join us this year, with more info available soon.

Electric Grid Control Room at CIR

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

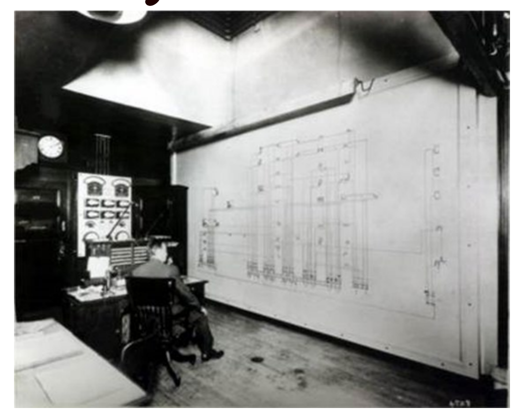
Announcements

- Start reading Chapters 1 and 2 from the book (Chapter 1 is Introduction, Chapter 2 is Electromagnetic Transients)
- We'll be using PowerWorld Simulator fairly extensively in this class, both the educational and professional versions
- Download the free 42 bus educational versions of PowerWorld Simulator at

  https://www.powerworld.com/gloveroverbyesarma
- On campus students consider signing up for the Energy and Power Group seminar on Fridays at 1130am in ETB 1020 (ECEN 681, Section 604)

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), 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!

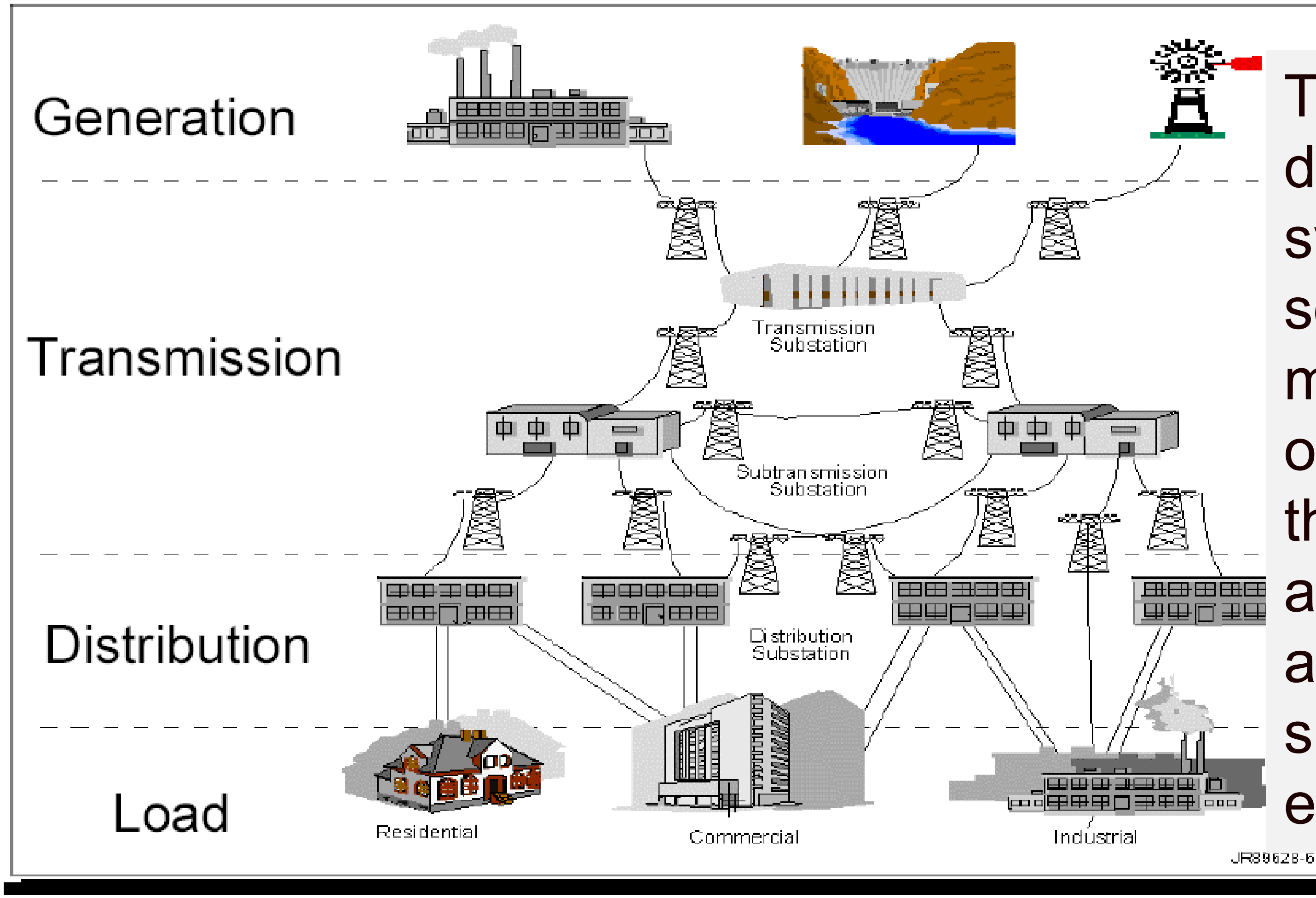
Power System Examples

- 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

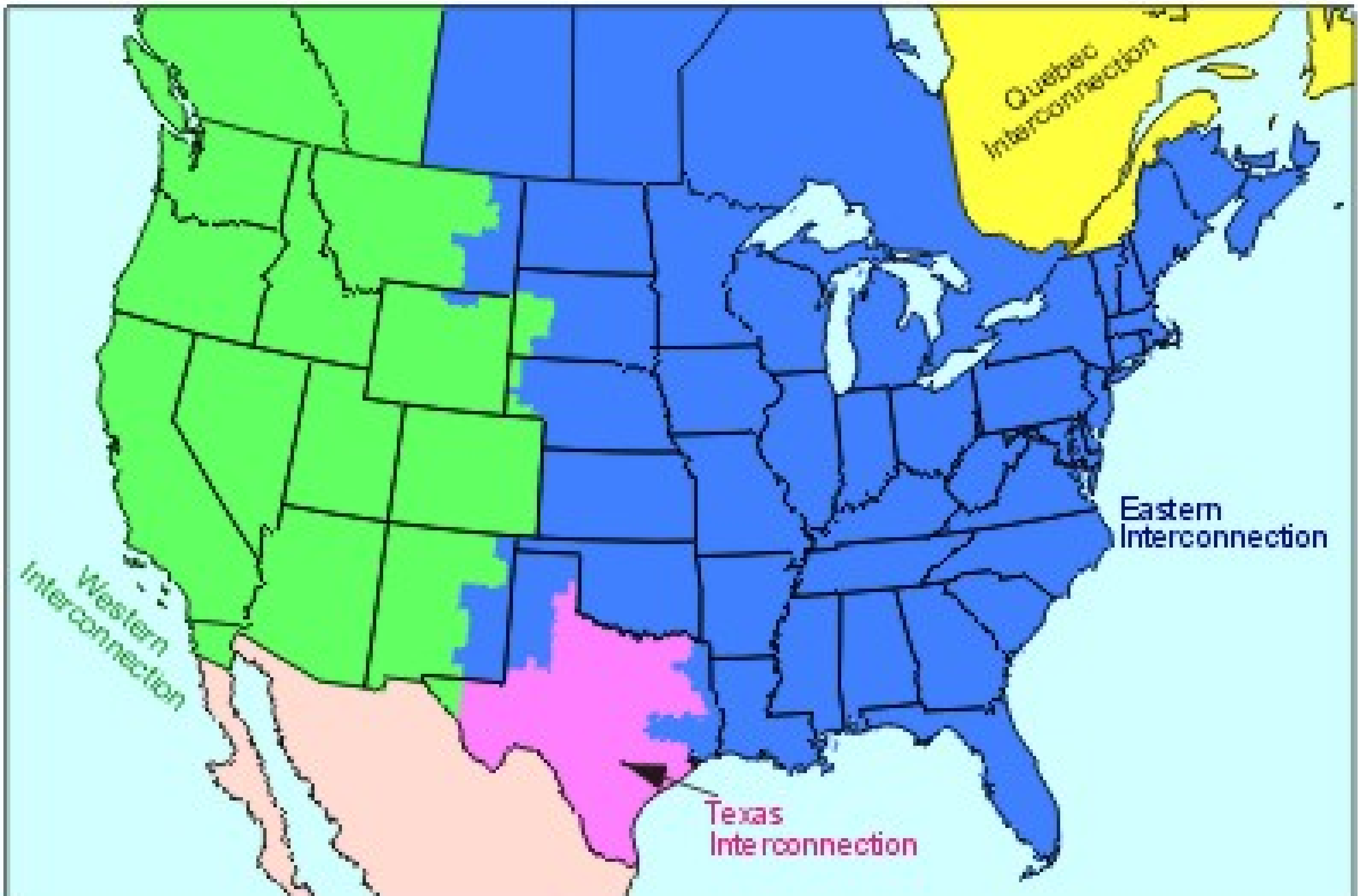
Three-Phase Systems

- 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

North America Interconnections



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

- Images show the frequency during the 2020 Super Bowl

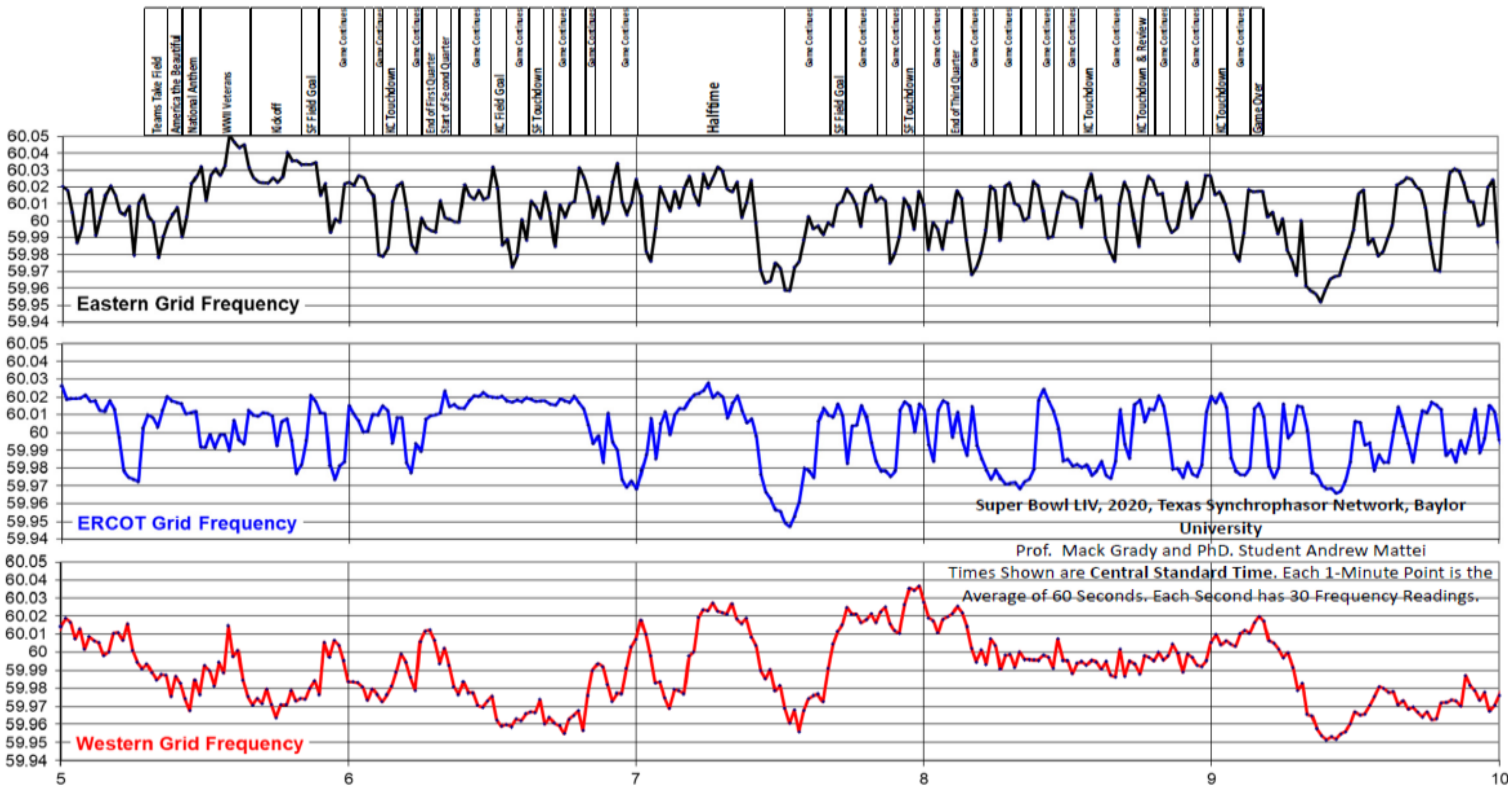
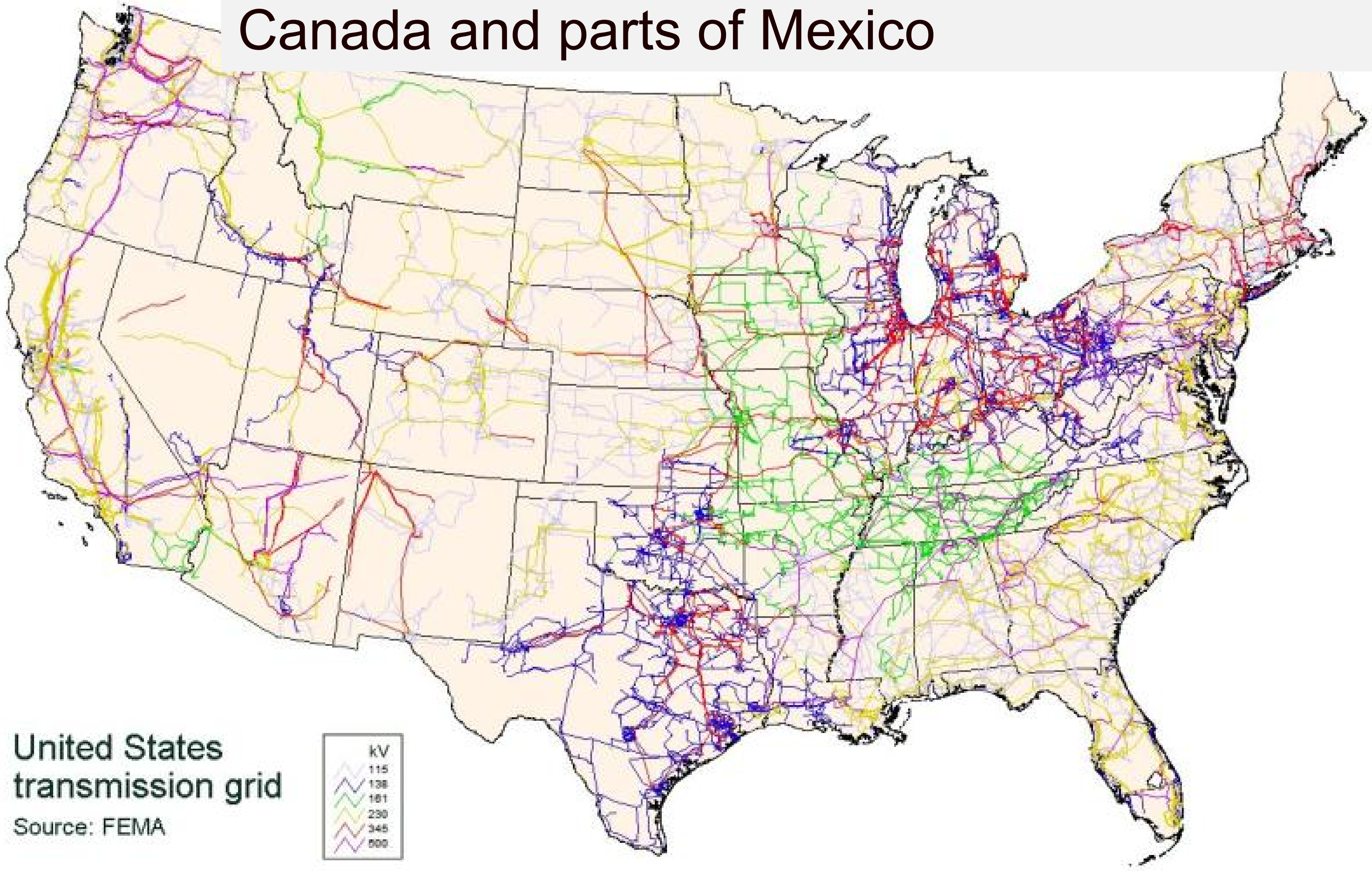


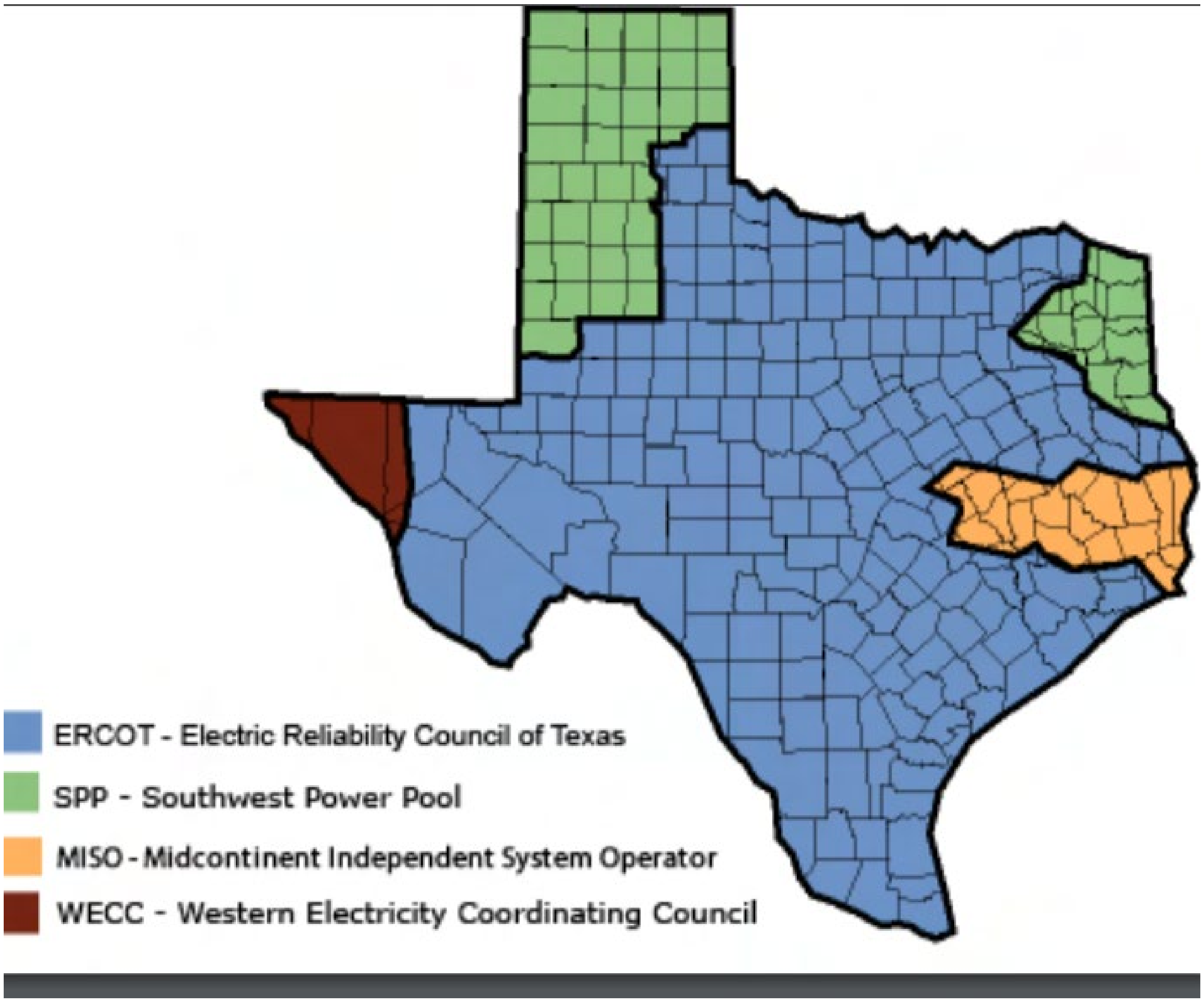
Image from Prof. Mack Grady of Baylor University

Continental US Transmission Grid

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

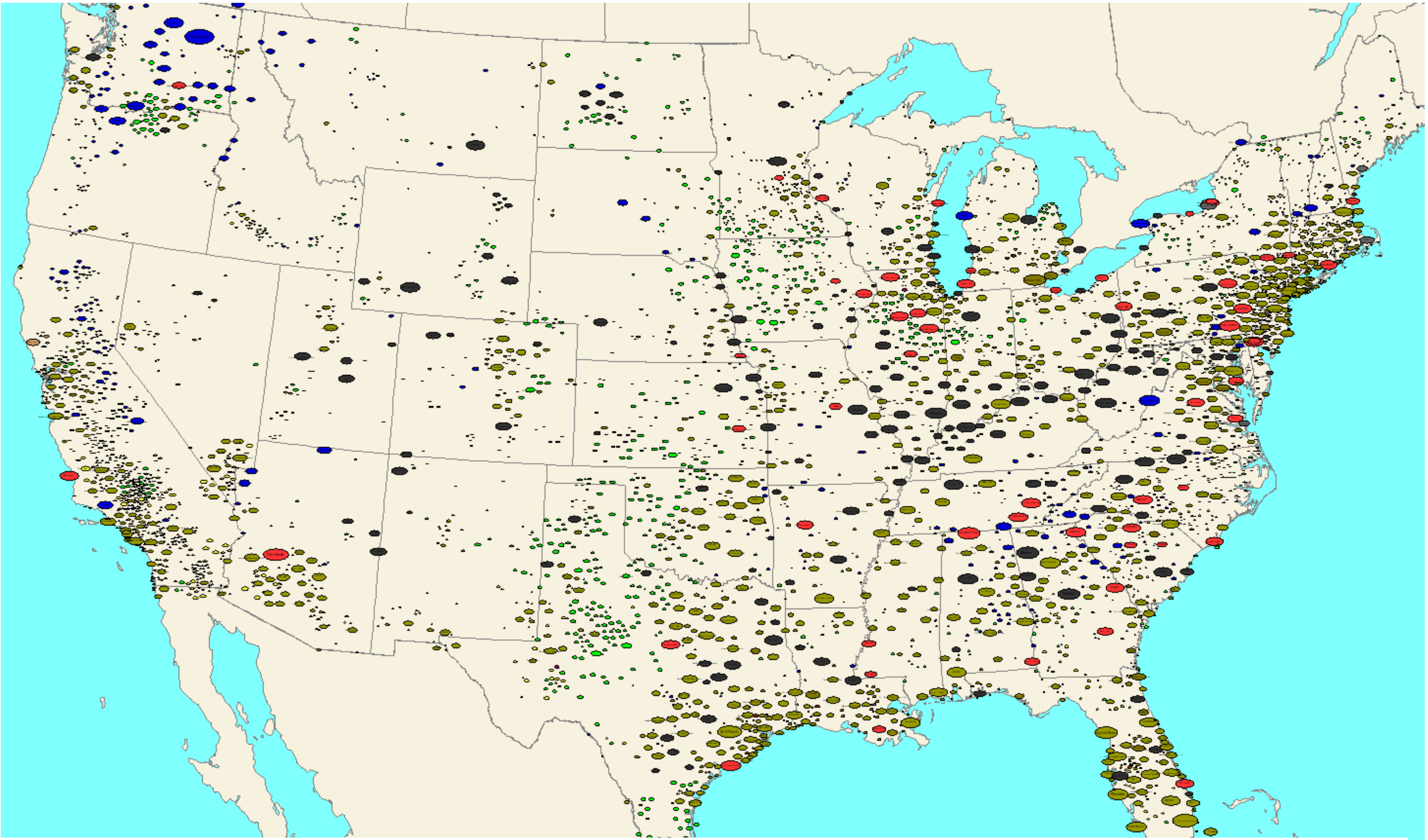


Electric Interconnections in Texas



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

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;

Electric Frequencies and Residential Voltages Worldwide

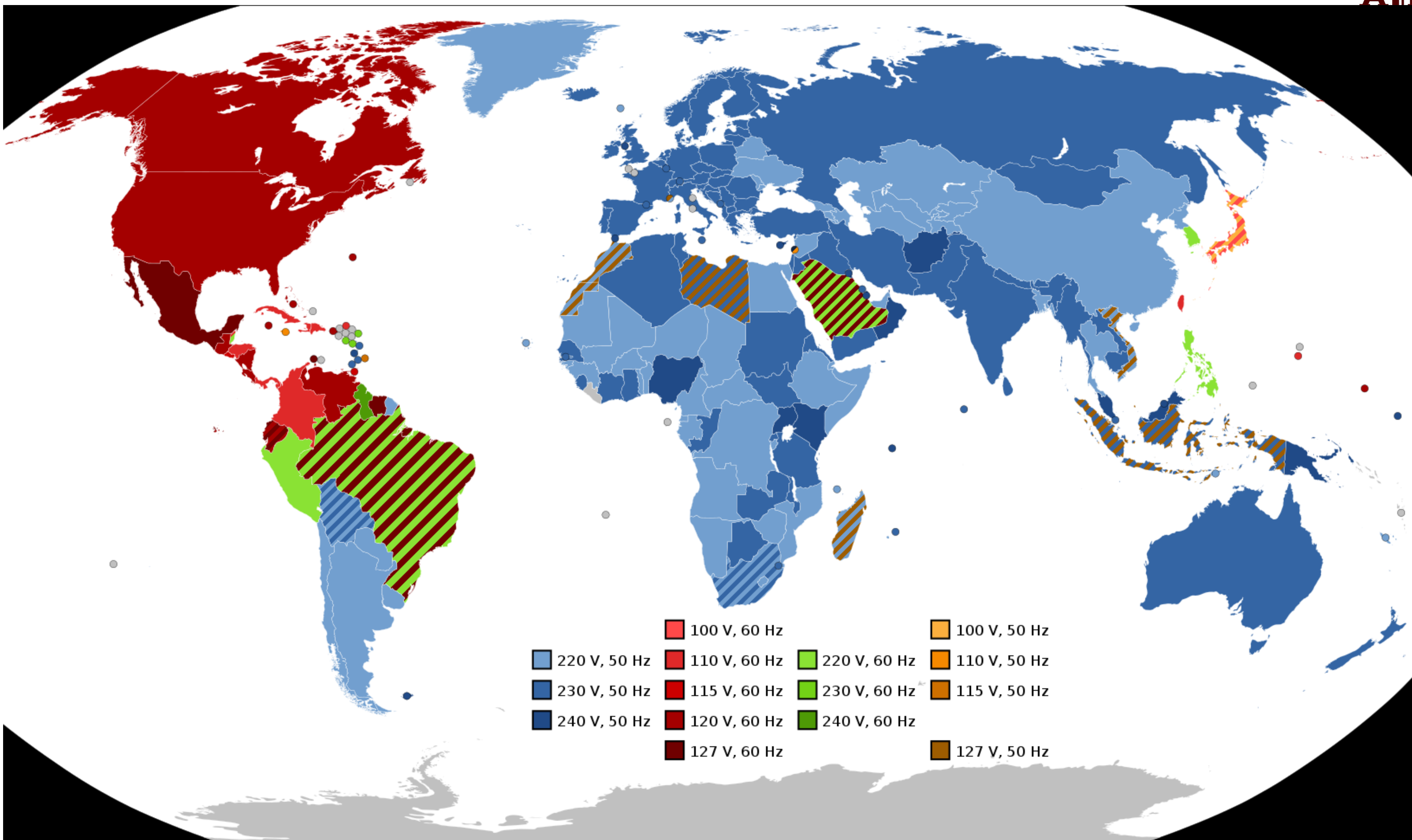


Image Source: en.wikipedia.org/wiki/Mains_electricity_by_country#/media/File:World_Map_of_Mains_Voltages_and_Frequencies,_Detailed.svg

Power System Time Frames

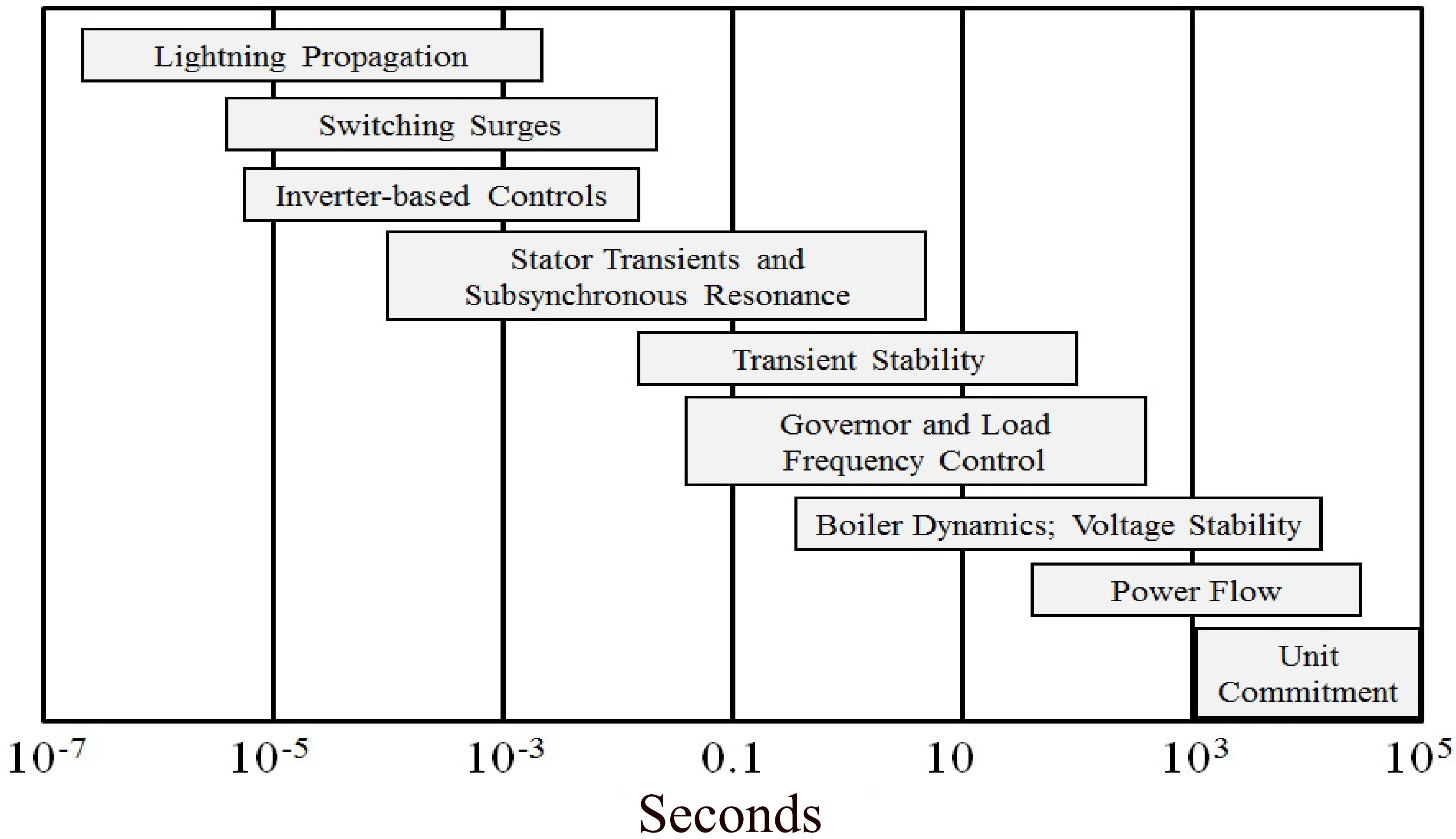


Image source: P.W. Sauer, M.A. Pai, Power System Dynamics and Stability, 1997, Fig 1.2, modified

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!