ECEN 615
Methods of Electric Power Systems Analysis

Lecture 1: Power Systems Overview

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TEXAS A&M UNIVERSITY

Course Mechanics

- In Fall 2020 ECEN 615 was suppose to be offered both live on campus and distance learning
- Now it is offered live via Zoom and distance learning, with students from both sections able to participate synchronously from 8 to 915am (Central Time) Tuesday and Thursday
  - I'll be emailing out the Zoom link to all the registered students
- The course has a public website as well as a private Canvas website
  - We'll post all material on Canvas, including the Zoom lectures
  - Much material will be on the public website, included the ppts of the lectures, but not the Zoom recordings

Syllabus Material

- The syllabus is posted in several locations
- The public website is
  - overbye.engr.tamu.edu/ecen-615-fall-2020/
- 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 book is A. J. Wood, B. F.Wollenberg, G. B. Sheble, *Power Generation, Operation and Control*, Third Edition, Wiley, 2013, ISBN-13: 978-0471790556.

Canvas

- Starting this year Texas A&M is transitioning to a new learning management system (LMS) known as Canvas
- We'll be using Canvas for ECEN 615 this semester, though I'm not sure yet which features we'll be using
- The login for Canvas is at lms.tamu.edu
- There is training available on the site, and I think you'll find it fairly intuitive
- Canvas will not become active for ECEN 615 until the first day of class

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 29 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

TAMU Energy and Power Group (EPG)

Electric Grid Control Room at CIR

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 working at Stanford, and Amanda a junior at Belmont in environmental sciences
- Jo just finished a master's in counseling, we attend Grace Bible Church in College Station (and teach the 3rd and 4th graders sometimes); I am the faculty advisor for Christian Engineering Leaders; I also like swimming, biking and watching football (Aggies and Packers!)

About TA Julian Thekkemathiote

- Second year Master's student
  - B.Tech (EE, Vellore Institute of Technology, India)
  - Research Assistant since May 2020
  - Research Area
    - Grid Interconnection Studies
    - Price Response Demand
  - Advisor: Prof. Tom Overbye
  - Hobbies: Soccer, hiking

Bastrop, Texas, 2020

The control room at the A&M Center for Infrastructure Renewal (CIR)

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
- Download the free 42 bus educational versions of PowerWorld Simulator at

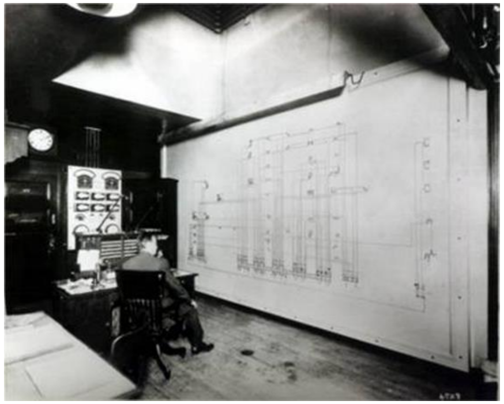
  https://www.powerworld.com/gloveroverbyesarma

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"

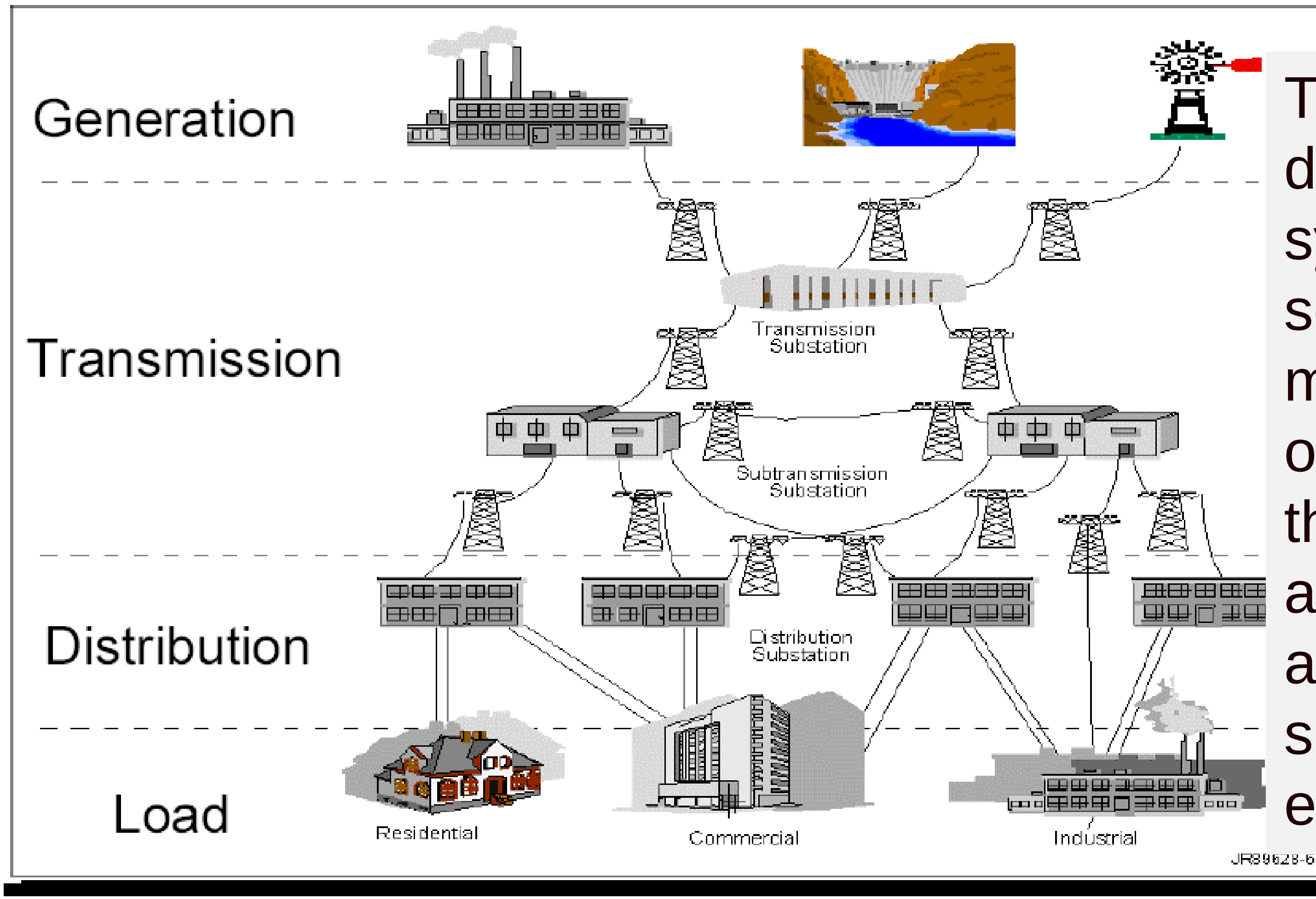
Power System Examples

- 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 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

Electric Grid Time Frames

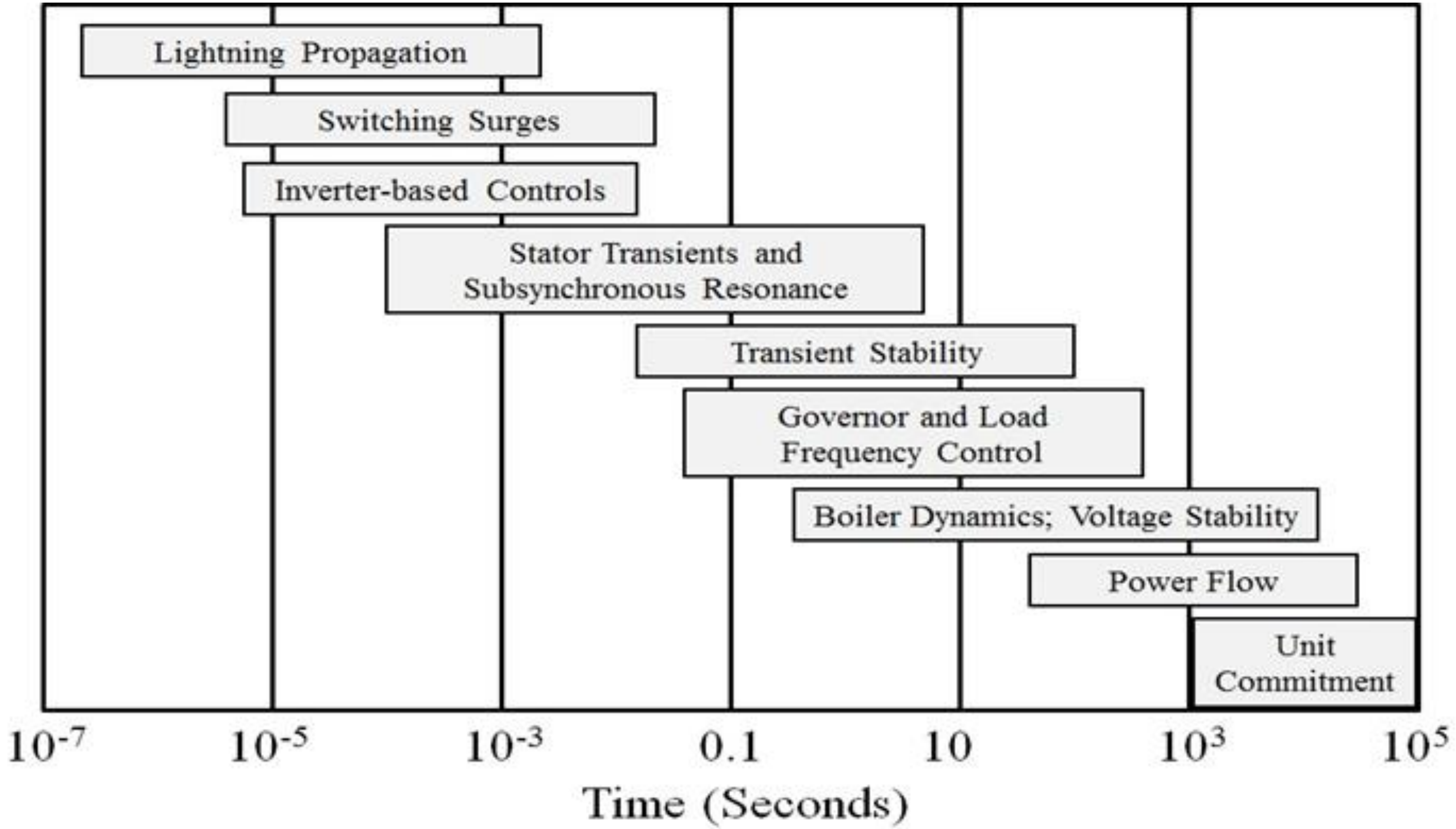


Image: Sauer, P.W., M. A. Pai, Power System Dynamics and Stability, Stripes Publishing, 2007

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 x 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

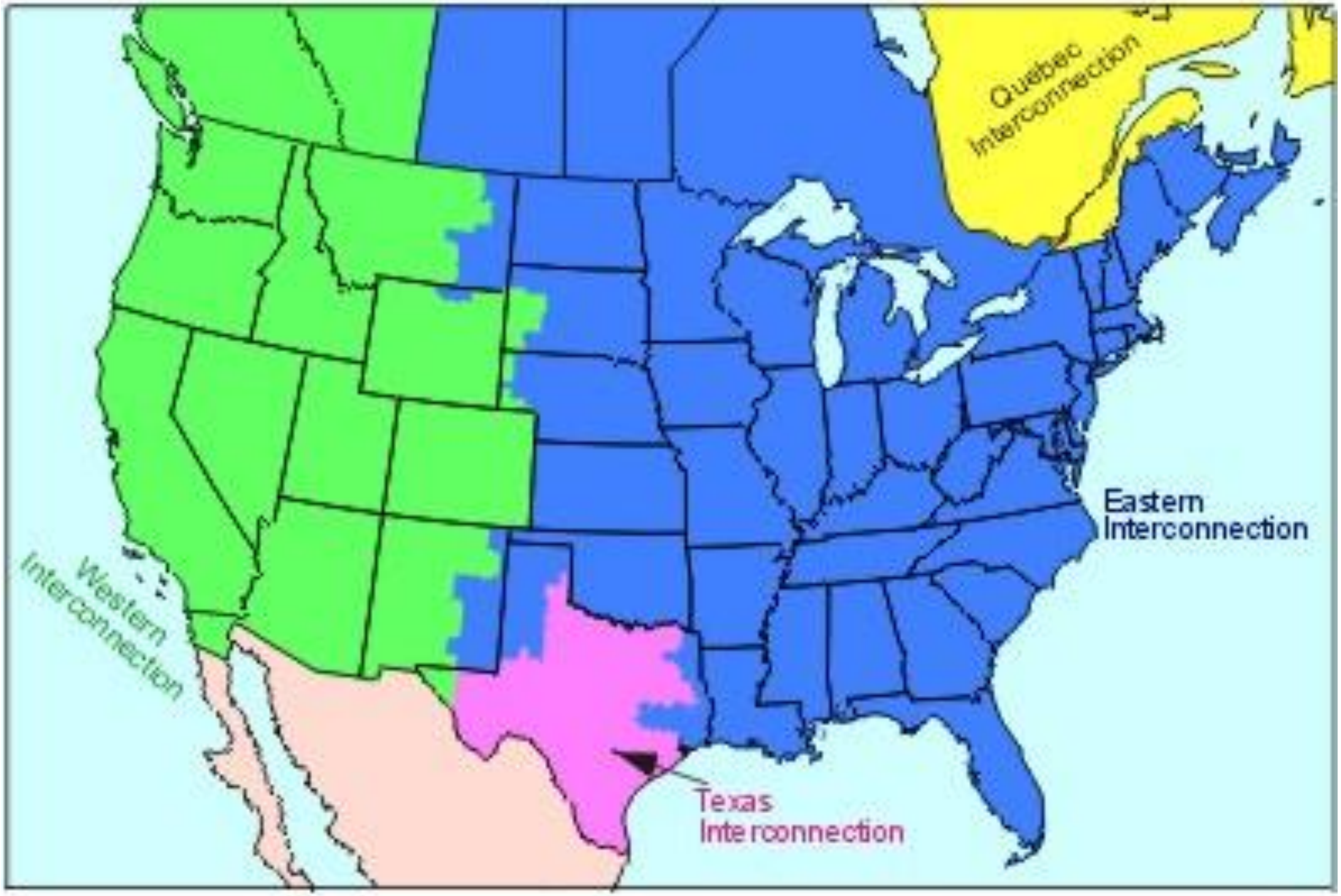
Three-Phase Systems

- 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

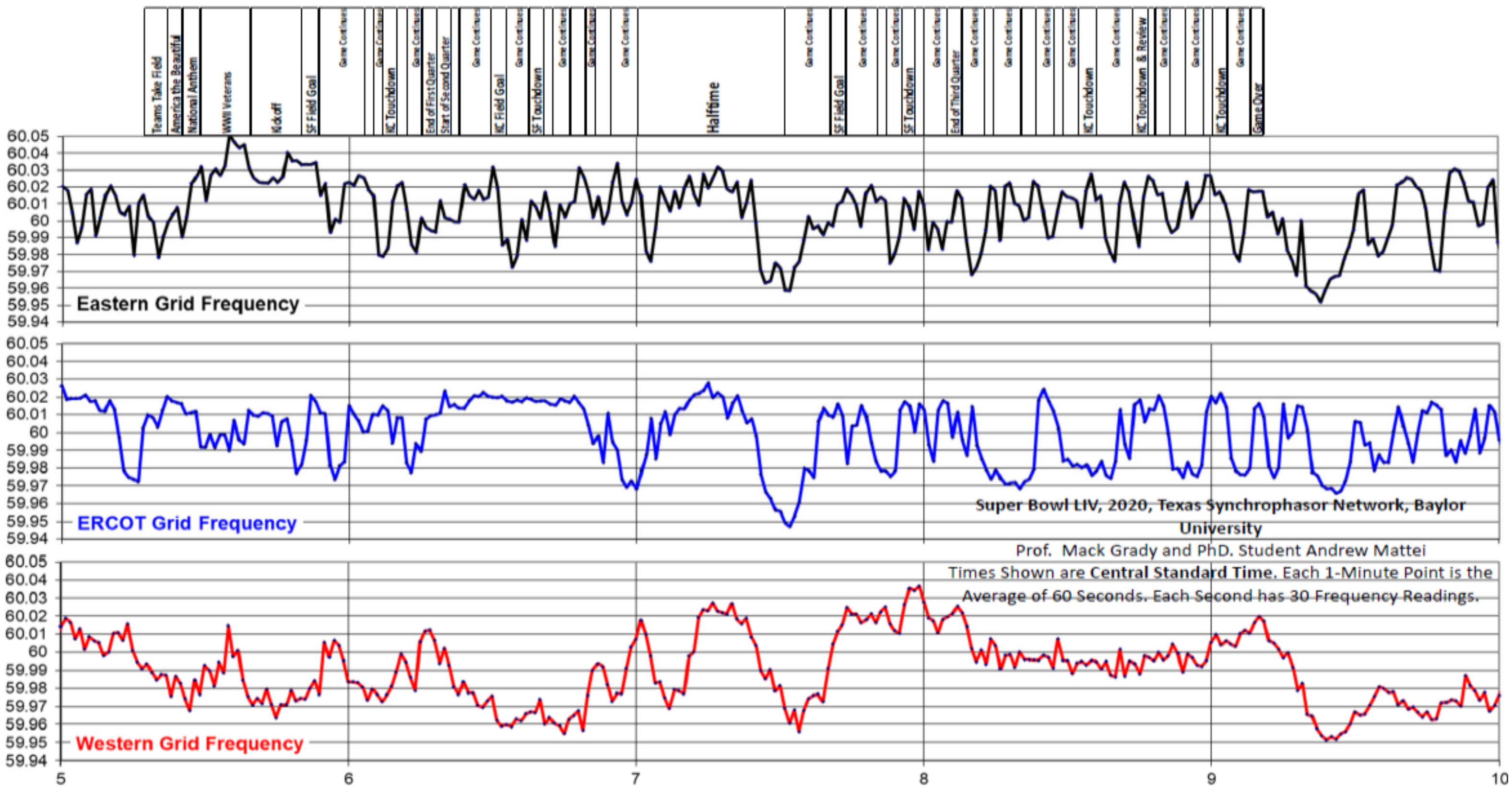
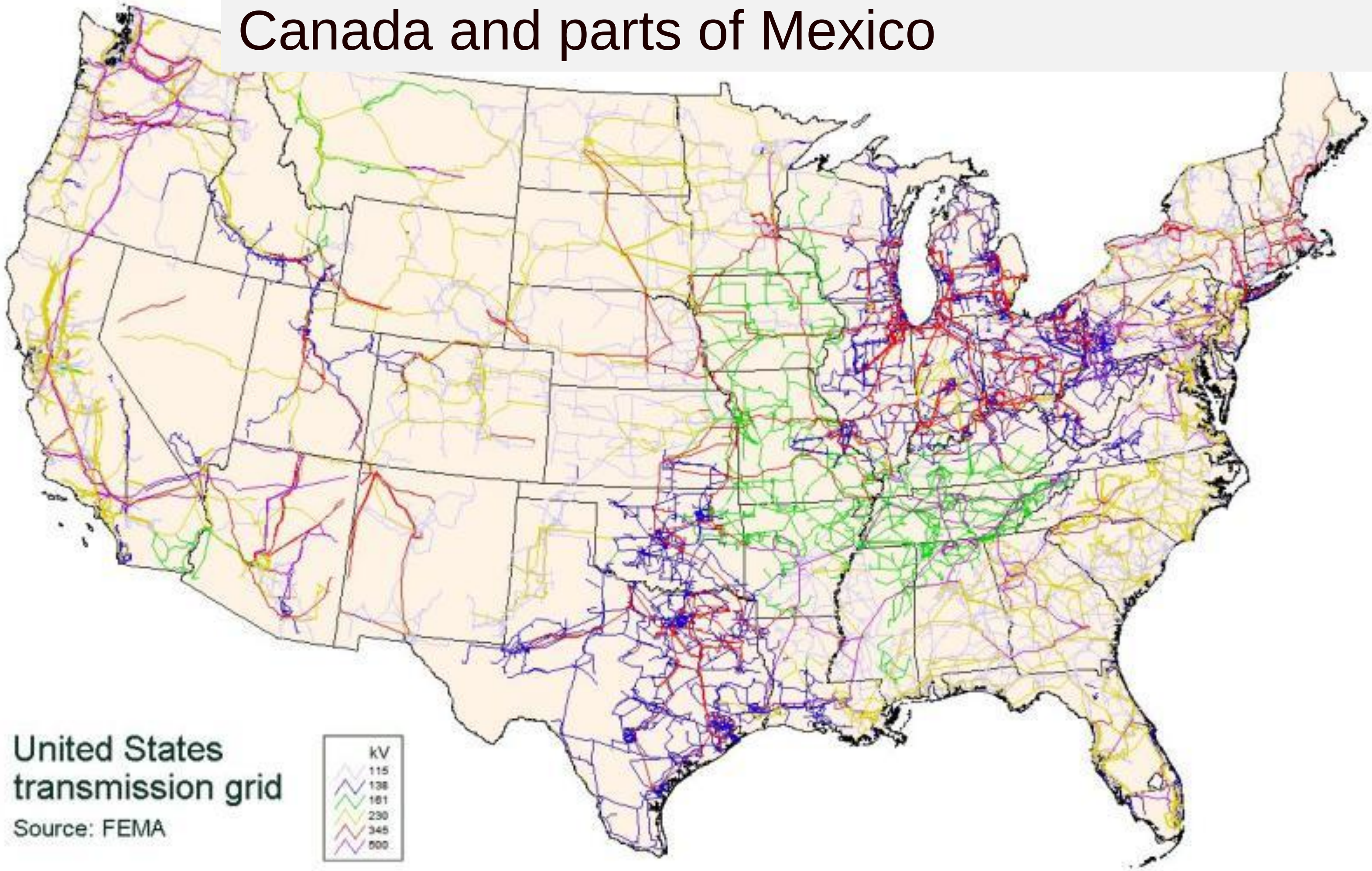


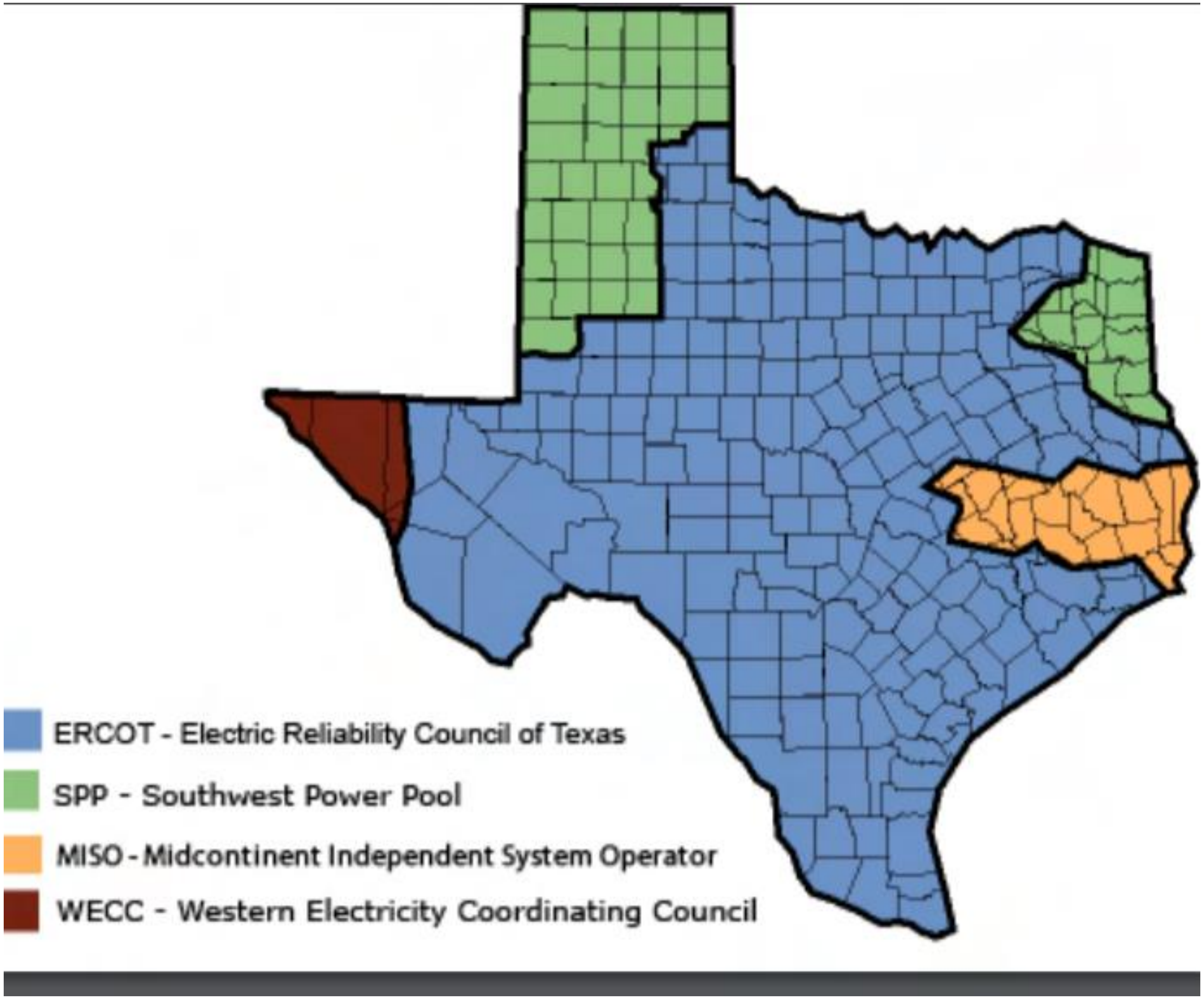
Image from Prof. Mack Grady of Baylor University

Continental US Transmission Grid

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

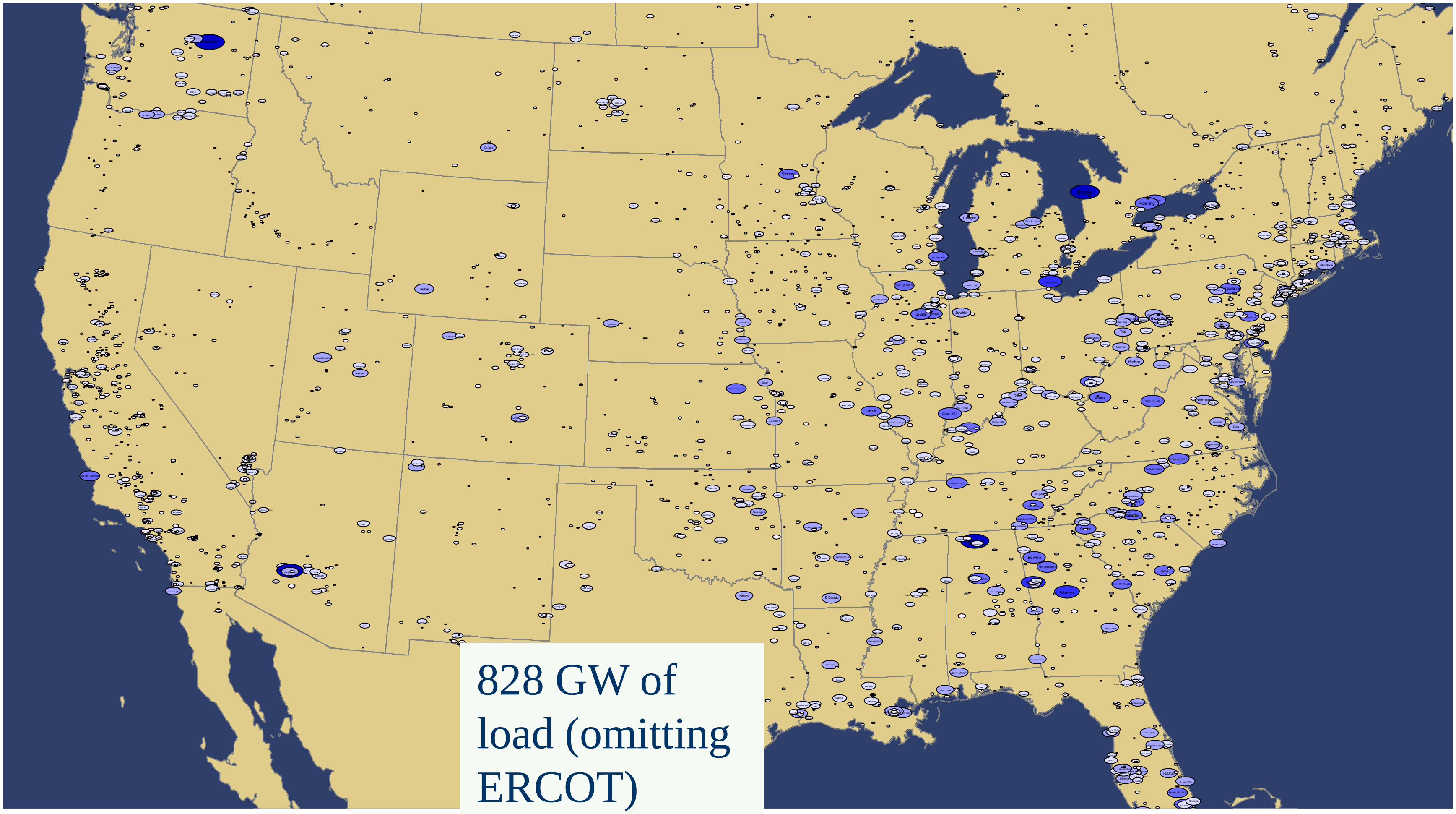


Electric Interconnections in Texas



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

North America Electric Grid Model Generation



828 GW of load (omitting ERCOT)

Electric Frequencies and Residential Voltages Worldwide

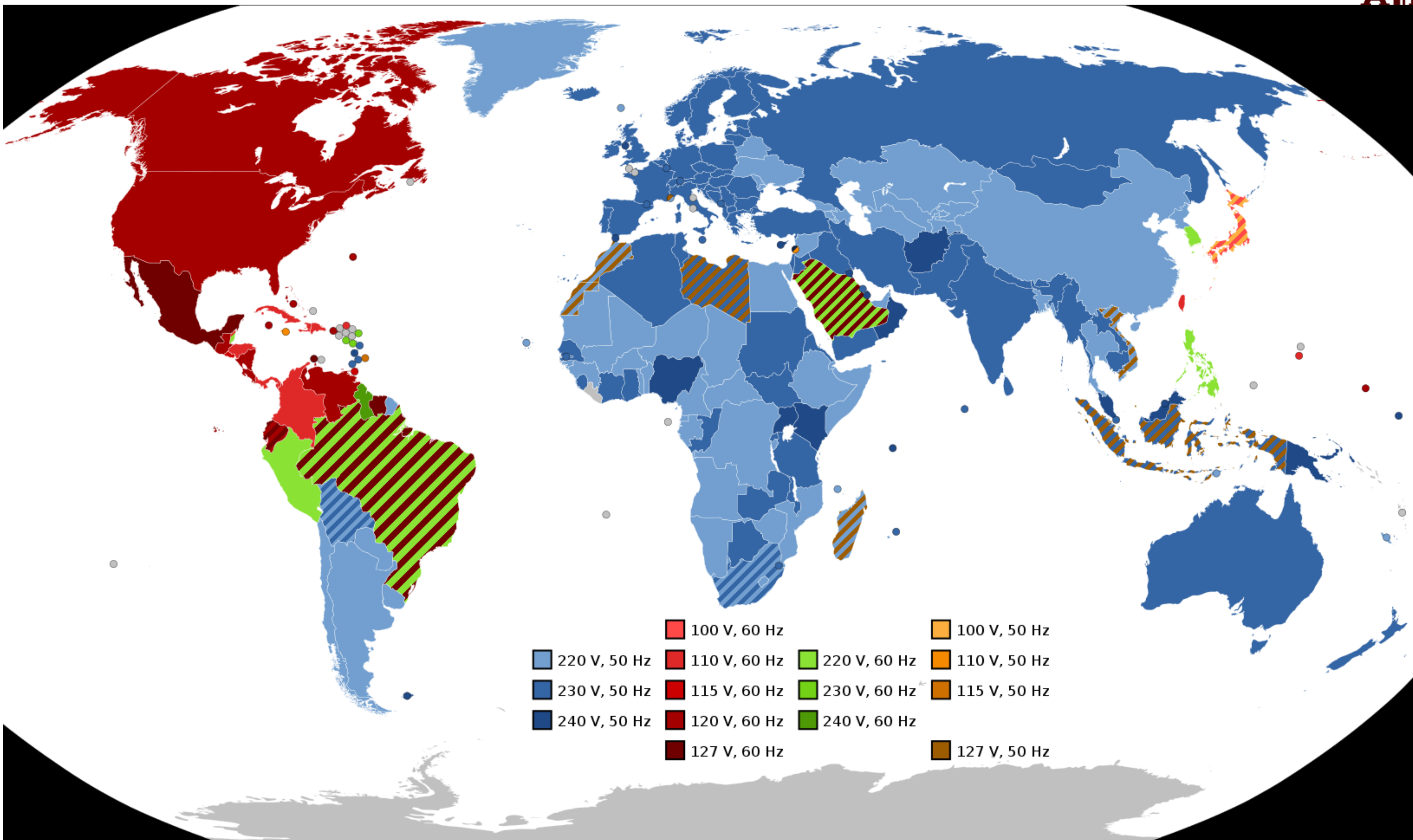


Image Source:
en.wikipedia.org/wiki/Mains_electricity_by_country#/media/File:World_Map_of_Mains_Voltages_and_Frequencies,_Detailed.svg