ECEN 667
Power System Stability

Lecture 1: Overview and Numeric Solution of Differential Equations

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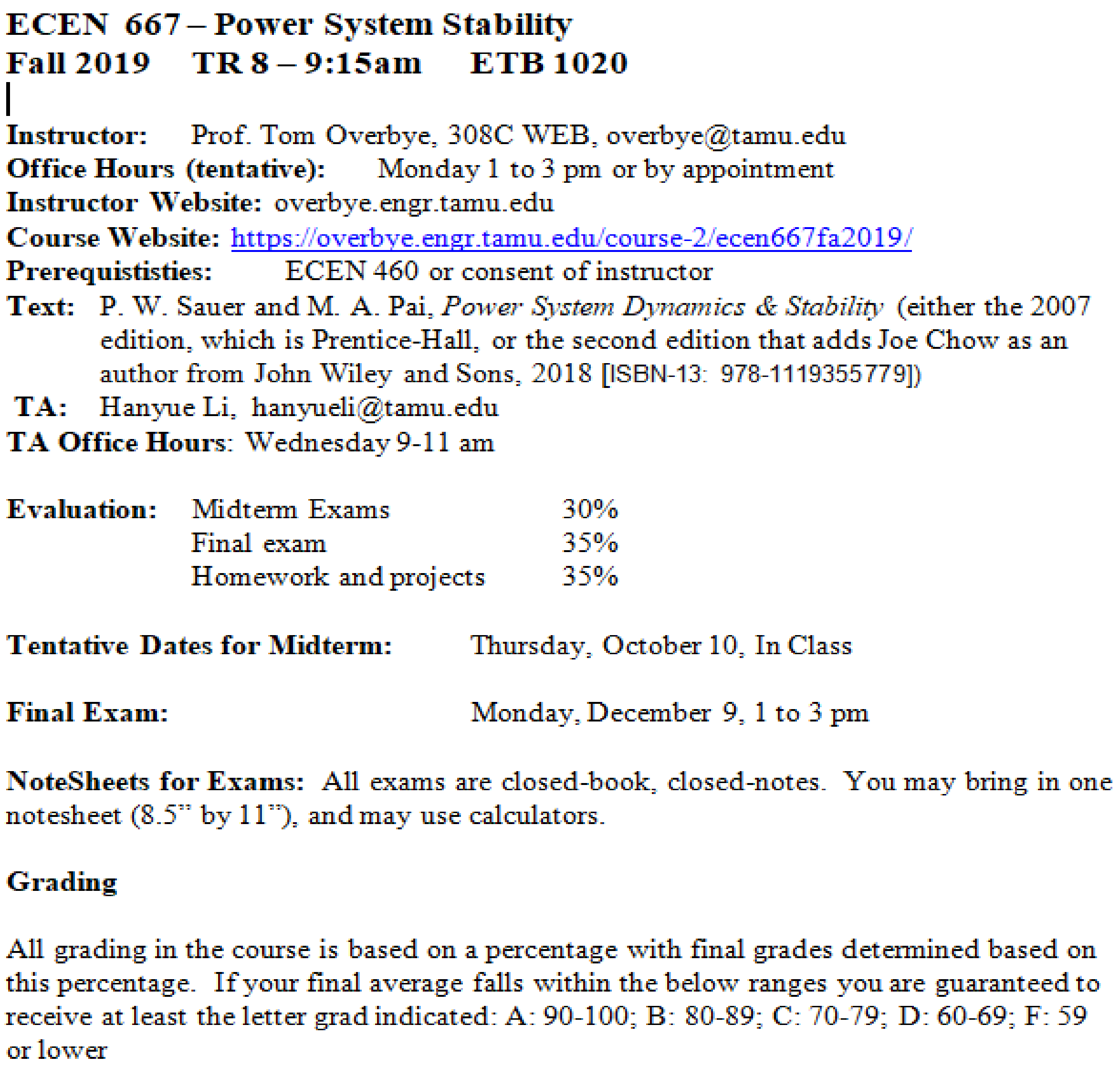
Prof. Tom Overbye
Dept. of Electrical and Computer Engineering
Texas A&M University
overbye@tamu.edu

Syllabus



ECEN 667 – Power System Stability
Fall 2019 TR 8 – 9:15am ETB 1020

Instructor: Prof. Tom Overbye, 308C WEB, overbye@tamu.edu
Office Hours (tentative): Monday 1 to 3 pm or by appointment
Instructor Website: overbye.engr.tamu.edu
Course Website: https://overbye.engr.tamu.edu/course-2/ecen667fa2019/
Prerequististies: ECEN 460 or consent of instructor
Text: P. W. Sauer and M. A. Pai, *Power System Dynamics & Stability* (either the 2007 edition, which is Prentice-Hall, or the second edition that adds Joe Chow as an author from John Wiley and Sons, 2018 [ISBN-13: 978-1119355779])
TA: Hanyue Li, hanyueli@tamu.edu
TA Office Hours: Wednesday 9-11 am

Evaluation:	Midterm Exams	30%
	Final exam	35%
	Homework and projects	35%

Tentative Dates for Midterm: Thursday, October 10, In Class

Final Exam: Monday, December 9, 1 to 3 pm

NoteSheets for Exams: All exams are closed-book, closed-notes. You may bring in one notesheet (8.5" by 11"), and may use calculators.

Grading

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

The 2006 version of the book is available at www.stipes.com/catalog/electrical-engineering/power-system-dynamics-stability/19

ECEN 667 Public Website

- Publicly accessible website is

  overbye.engr.tamu.edu/course/ecen667fa2019/

  - Notes for the upcoming lecture will be posted ahead of time
- The 2017 version of the course is available at

  overbye.engr.tamu.edu/course/ecen667fa2017/

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 28 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 and Summer 2019

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 Hanyue Li

- Third year PhD student
  - BSc (EE, Illinois Institute of Technology)
  - MSc (ECE, Carnegie Mellon University)
  - PhD Research Area
    - Power Systems Modeling and Simulation
    - Large-Scale Systems
  - Advisor: Prof. Tom Overbye
  - Hobbies & Interests: Rock climbing, hiking
  - Former Co-director, Texas Power and Energy (TPEC)

Conference

- Vice Chair, TAMU IEEE PES-IAS-PELS

student chapter

Bouldering in South Lake Tahoe, California

TPEC 2019 in College Station, Texas

Electric Grid Control Room at CIR

TAMU ECE Energy and Power Group Picnic: September 27, 2019

This picture is from our event last spring. If you would like to join us this year, RSVP to Alex Bello (zandra23@ece.tamu.edu)

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

Power System Time Frames

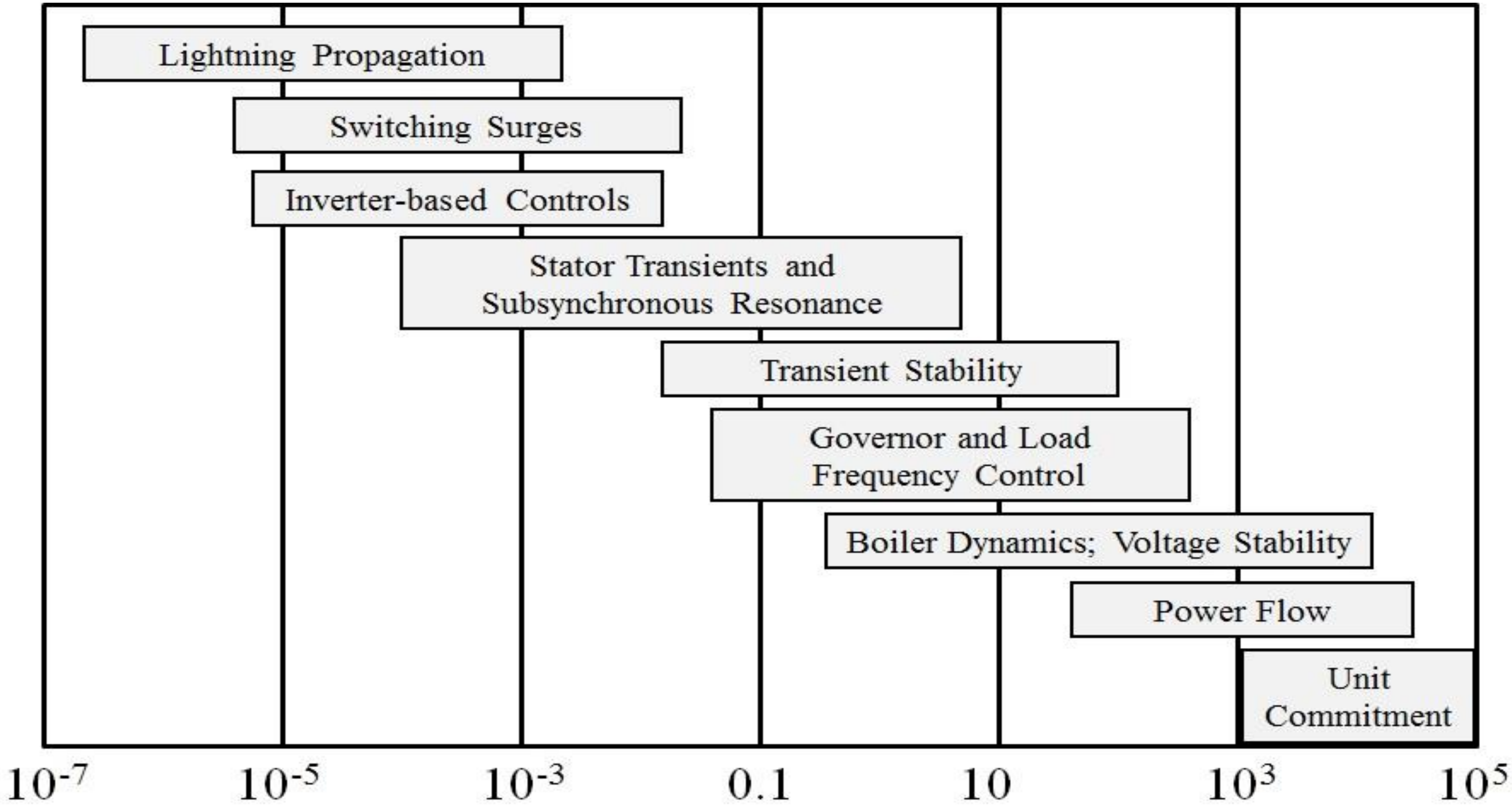


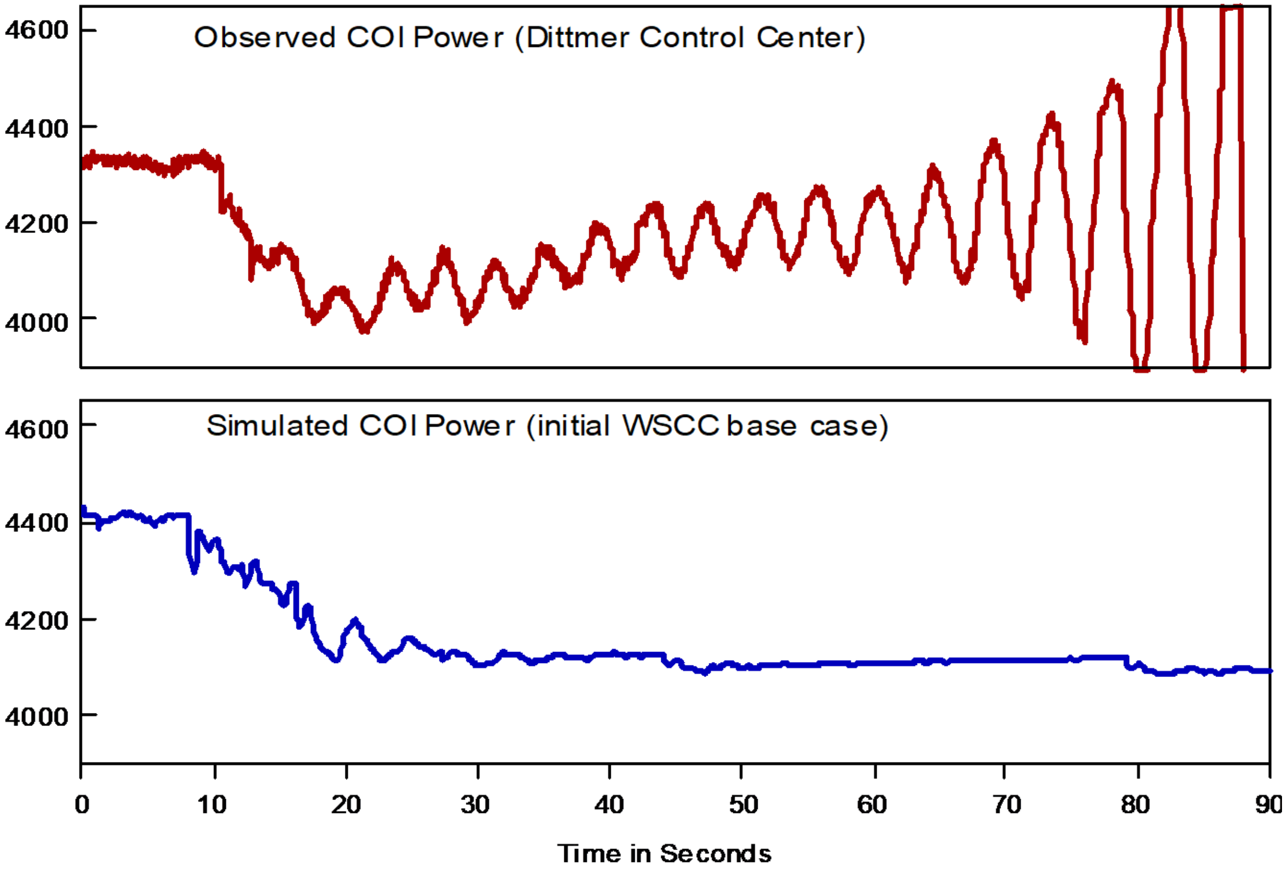
Image source: P.W. Sauer, M.A. Pai, Power System Dynamics and Stability, 1997, Fig 1.2, modified

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!

Dynamics Example 1

1996: Transient Stability Model Errors Lead to Blackouts



Dynamics Example: August 14 Blackout

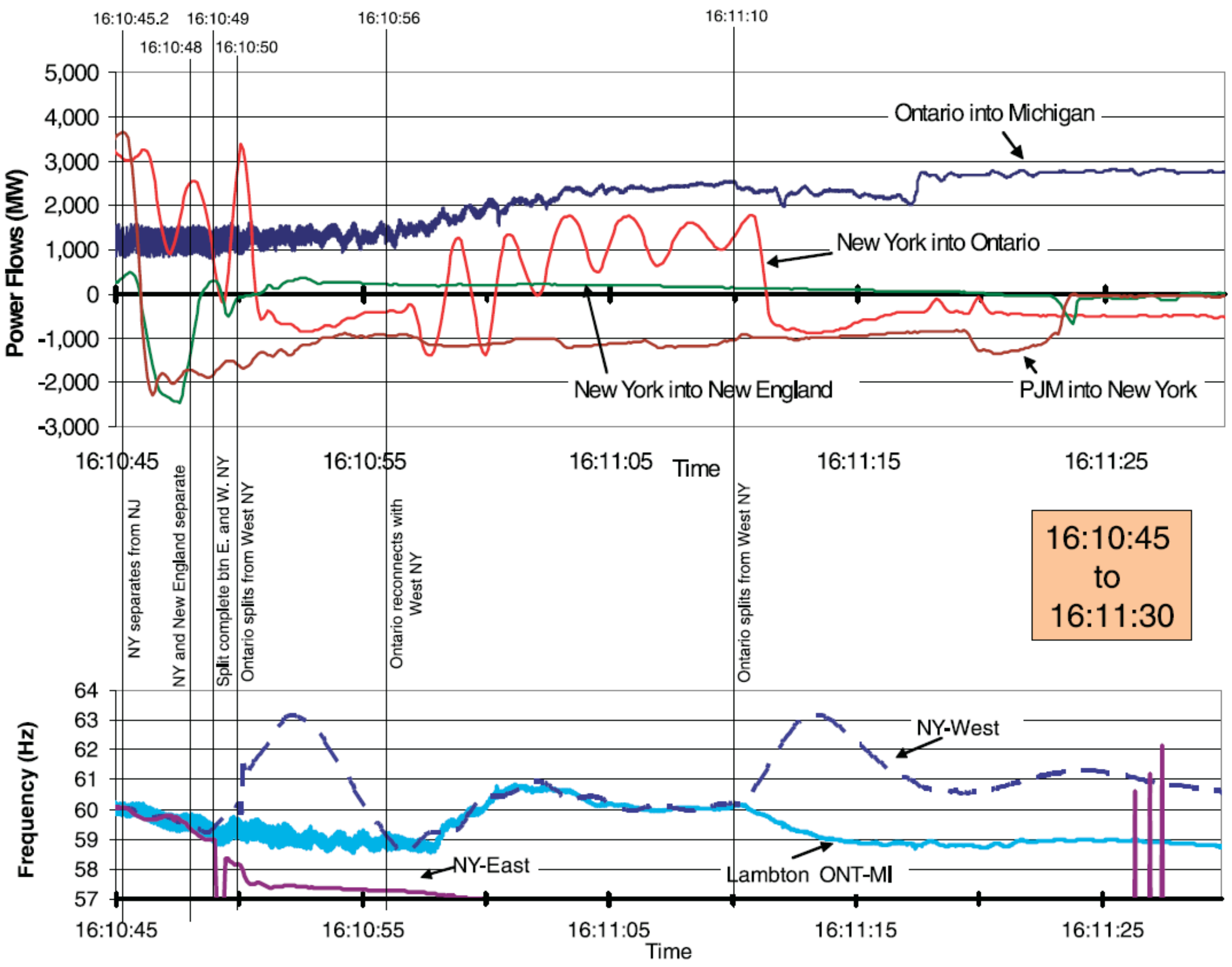
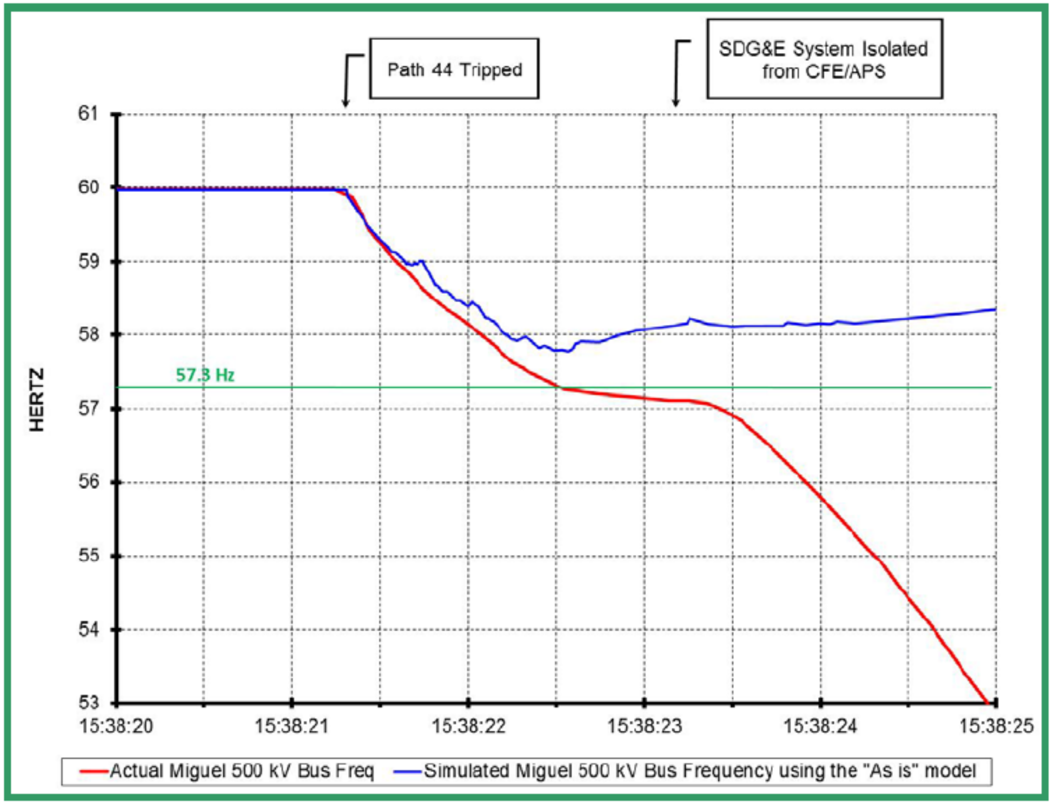


Image from August 14, 2003 Blackout Final Report, energy.gov, Figure 6.26

Dynamics Example 3

Figure 14: Actual and Simulated Frequency at Miguel 500 kV Bus



We've come a long ways since 1996 towards improved simulations. Still, a finding from the 2011 Blackout is the simulations didn't match the actual system response and need to be improved.

Source: *Arizona-Southern California Outages on September 8, 2011 Report*, FERC and NERC,April 2012

Models and Their Parameters

- Models and their parameters are often tightly coupled
  - The parameters for a particular model might have been derived from actual results on the object of interest
- Changing the model (even correcting an "incorrect" simulation implementation) can result in unexpected results!
- Using a more detailed simulation approach without changing the model can also result in incorrect results
  - More detailed models are not necessarily more accurate

Static versus Dynamic Analysis

- Statics versus dynamics appears in many fields
- An equilibrium point is a point at which the model is not changing
  - Real systems are always changing, but over the time period of interest an unchanging system can be a useful approximation
- Static analysis looks at how the equilibrium points change to a change in the model
  - Power system example is power flow
- Dynamic analysis looks at how the system responds over time when it is perturbed away from an equilibrium point
  - Power system example is transient stability

Slow versus Fast Dynamics

- Key analysis question in setting up and solving models is to determine the time frame of interest
- Values that change slowly (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

Positive Sequence versus Full Three-Phase

- Large-scale electrical systems are almost exclusively three-phase. Common analysis tools such as power flow and transient stability often assume balanced operation
  - This allows modeling of just the positive sequence though full three-phase models are sometimes used particularly for distribution systems
  - Course assumes knowledge of sequence analysis
- Other applications, such as electromagnetic transients (commonly known as electromagnetic transients programs [EMTP]) consider the full three phase models

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)

PowerWorld Simulator

- Class will make extensive use of PowerWorld Simulator and DS. If you do not have a copy of version 21, 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. Transient stability aspects will be covered in class
- Free training material is available at

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

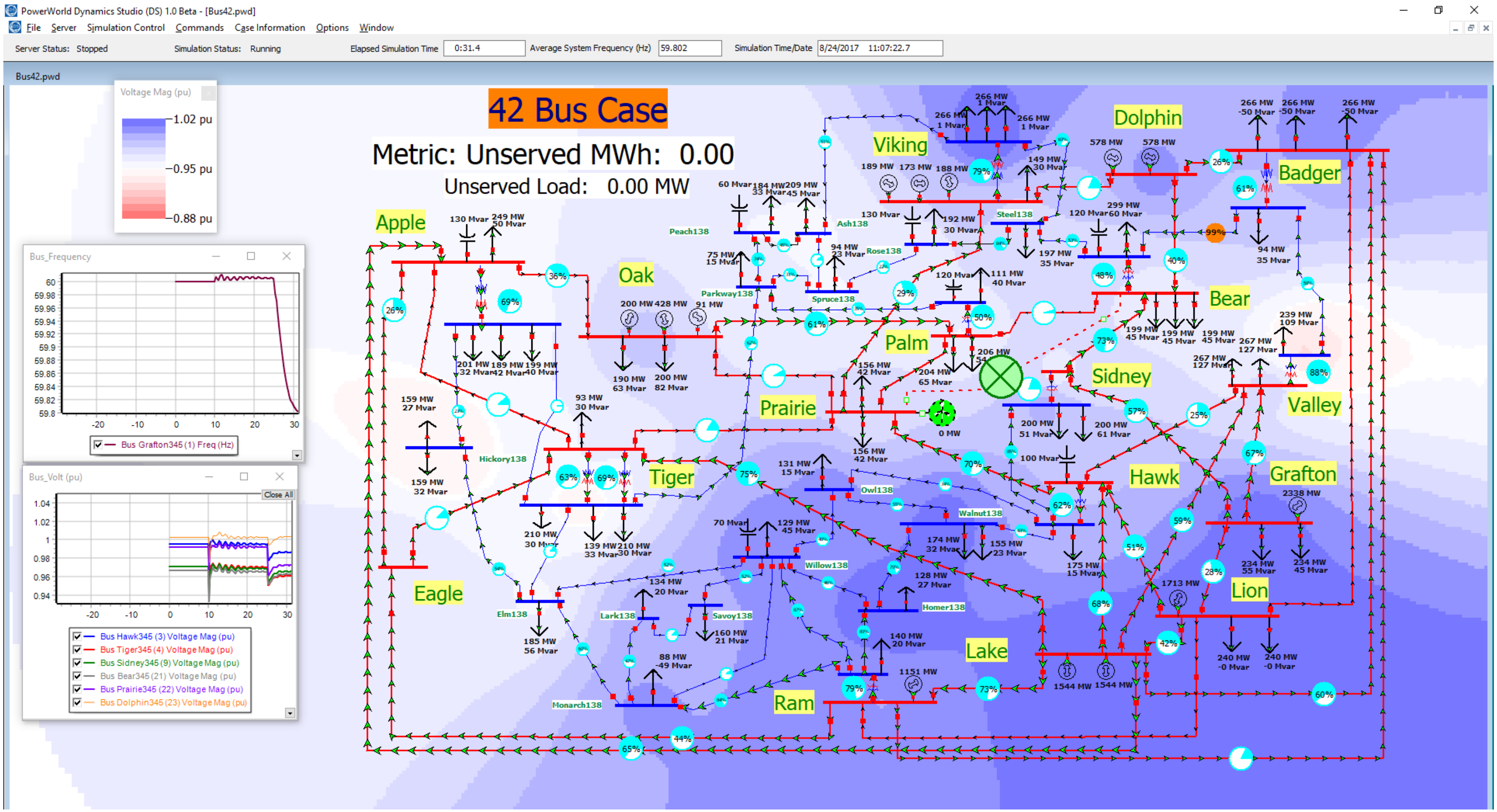
Power Flow Versus Dynamics

- The power flow is used to determine a quasi steady-state operating condition for a power system
  - Goal is to solve a set of algebraic equations $\mathbf{g(x) = 0}$
  - Models employed reflect the steady-state assumption, such as generator PV buses, constant power loads, LTC transformers
- Dynamic analysis is used to determine how the system changes with time, usually after some disturbance perturbs it away from a quasi-steady state equilibrium point

Example: Transient Stability

- Transient stability is used to determine whether following a disturbance (contingency) the power system returns to a steady-state operating point
  - Goal is to solve a set of differential and algebraic equations, $d\mathbf{x}/dt = \mathbf{f}(\mathbf{x},\mathbf{y})$, $\mathbf{g}(\mathbf{x},\mathbf{y}) = \mathbf{0}$
  - Starts in steady-state, and hopefully returns to steady-state.
  - Models reflect the transient stability time frame (up to dozens of seconds), with some values assumed to be slow enough to hold constant (LTC tap changing), while others are still fast enough to treat as algebraic (synchronous machine stator dynamics, voltage source converter dynamics).

Interactive Simulation: PowerWorld Dynamics Studio (DS)



PowerWorld Dynamics Studio (DS) 1.0 Beta - [Bus42.pwd]

Server Status: Stopped

Simulation Status: Running

Elapsed Simulation Time: 0:31.4

Average System Frequency (Hz): 59.802

Simulation Time/Date: 8/24/2017 11:07:22.7

42 Bus Case

Metric: Unserved MWh: 0.00

Unserved Load: 0.00 MW