Teaching Electric Power Systems using MATLAB and Simulink

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THE UNIVERSITY of TULSA

Agenda

MathWorks at the University of Tulsa

- **ECE's usage of MATLAB / Simulink**
- **ECE 3033 Electric Power Systems course**

Engineering Labs

- Importance of Engineering Labs
- Why the change to Virtual Power Labs

ECE 3033 Virtual Power Labs

- Implementation and Development Timeline
- Virtual Power Lab Design Features
- Virtual Power Lab Demonstration
- Student Feedback
- Benefits of a Virtual Lab

Evolving the Virtual Lab Concept

- Next Steps in Evolving the Virtual Lab
- Power Lab Revisions
- Integrating Power Lab Models into the classroom
- Three-Phase Power System Demonstration using Live Editor

Summary and Acknowledgements

University of Tulsa's Electrical and Computer Engineering Department Classroom and Lab Usage of MATLAB and Simulink

Academic Year	Course Number	Course Title	Use
Sophomore	ECE 2003	Electric Circuit Analysis	Solve system of equations and perform complex algebra - Dr. Surendra Singh
	ECE 2161	Digital Lab	Programming Arduinos with Digital Functions and basic Hardware-in-the-Loop Simulation - Dr. Nathan Hutchins
Junior	ECE 3113	Signals and Linear Systems	Fourier series approximation, filtering - Dr. Heng-Ming Tai
	ECE 4043	Electronics II	Simulate electronic circuits - Dr. Peter LoPresti
	ECE 4041	Electronics Lab	
	ECE 4053	Control Systems	Performance evaluation of PID control, design by root-locus and Bode techniques - Dr. Heng-Ming Tai
Senior	ECE 4073	Communication Systems	Spectrum representation and modulation simulation - Dr. Heng-Ming Tai
	ECE 4353/6723 / CS 4753	Robotics I	Modeling dynamics, control system design, visualization, and solving simultaneous equations - Dr. Loyd Hook
	ECE 5353/7353	Aircraft Systems, Simulation, and Control	
Graduate	EE 7023	Advanced Electromagnetics	Develop Method of Moments code for scattering from cylinders - Dr. Surendra Singh

ECE 3033 Electric Power Systems Course Work and Hardware Labs

Course Faculty: Professor Douglas Jussaume

Junior Level course

- Lecture on Magnetic Circuits/Three-Phase Systems / Transformers / DC & AC Motors and Generators
- No independent lab course – labs integrated into the course work

Integrated Labs

- Lab Introduction with a single-phase transformer and complex load
- Three-Phase System - DC Motor - AC Synchronous Generator

Lab Set-up

- Single lab benchtop
- Modular hardware - Motor/Generators, Transformers, Transmission Line, Complex loads
- Measure Voltage, Current, Frequency, Torque, and Speed
- Real time display of complex power, power factor, voltage/current, torque/speed, and frequency

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Importance of Engineering Labs

Support students in gaining experience and insight

- Build and Troubleshoot electrical circuits and systems
- Operate complex circuits and systems through system measurements over range of inputs and system changes
- **Relate classroom equivalent circuits to hardware performance**

Support student’s development of professional habits

- Perform lab operating as a lab team – collaborate–teamwork–work toward a common goal
- Most important – Communication – Learn to write a professional engineering lab report

Support the university’s mission

- Improve student retention and interest
- Increase the quality of our graduates

Why the Change to Virtual Power Labs?

University COVID Restrictions

- Physical distance
- Cleaning equipment and lab surfaces

Lab Restrictions

- Single bench area – very confined
- Single set of equipment / hardware

Result

- Logistical nightmare in attempting to perform labs in a team setting

Solution

- Develop virtual labs

Personnel Experience with MATLAB/Simulink

- NONE

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Virtual Power Lab Implementation and Development Timeline

May2020
Selected MathWorks Simulink to develop Virtual Power Labs

Early June2020
Met with MathWorks - download free MATLAB/Simulink

June2020
Started learning Simulink and developing initial models using Simscape Electrical

July2020 – Aug2020
Continued lab development using Specialize Power Systems

Sept – Nov2020
Junior class perform the virtual Power labs

Jan2021
Independent study with graduate and Senior students to continue Power Labs development

Virtual Power Labs Design Features

Control Panel

- Hand-input changes in the lab's parameters
- Display performance output for each change in input

Perform Open and Short Circuit Tests

- Determine equivalent circuit parameters
- Verify model performance using Power course's equivalent circuit models

Encourage the engineering student to "play" with the lab model

- Develop "feel" for the hardware and system performance

Guiding Design Philosophy: Mimic the Hardware Lab Experience

- "Mimic" meaning that the electrical engineering student must set-up the test conditions and then record performance data by hand.
- No single button to push to collect, record, download, and display the data

ECE 3033 Virtual Power Lab Technical Details

Three-Phase Power System

- Y-connected balanced Source and Load / 3-wire transmission line / Parallel RLC load impedance
- Measure the phase/line voltages, line current, real and reactive powers, and the power factor angle

Single Phase Transformer

- Step-up transformer with nonideal core / Parallel RLC load
- Measures the voltage and current on the source and load sides.

DC Shunt Motor

- 10 HP / 1750 RPM
- DC Terminal Voltage: adjustable DC voltage, 0 – 300 V DC
- Applied Mechanical Load Torque: adjustable load torque, 0 – 200 N-m

Synchronous Generator

- Synchronous Generator: 10.2 KVA, 460 V rms, 60 Hz, 1800 RPM, round rotor, Y-connected
- Parallel RLC load with adjustable circuit element values
- Adjustable generator speed, 0-3600 RPM, and field voltage, 0 – 150 V DC

ECE 3033 Virtual Lab Control Panel Technical Details

Three-Phase Power System

- **Control Panel:** On/off individual load circuit elements, adjust their values, and adjust the transmission line length

Single Phase Transformer

- **Control Panel:** On/off the individual load circuit elements and to perform open and short circuit tests

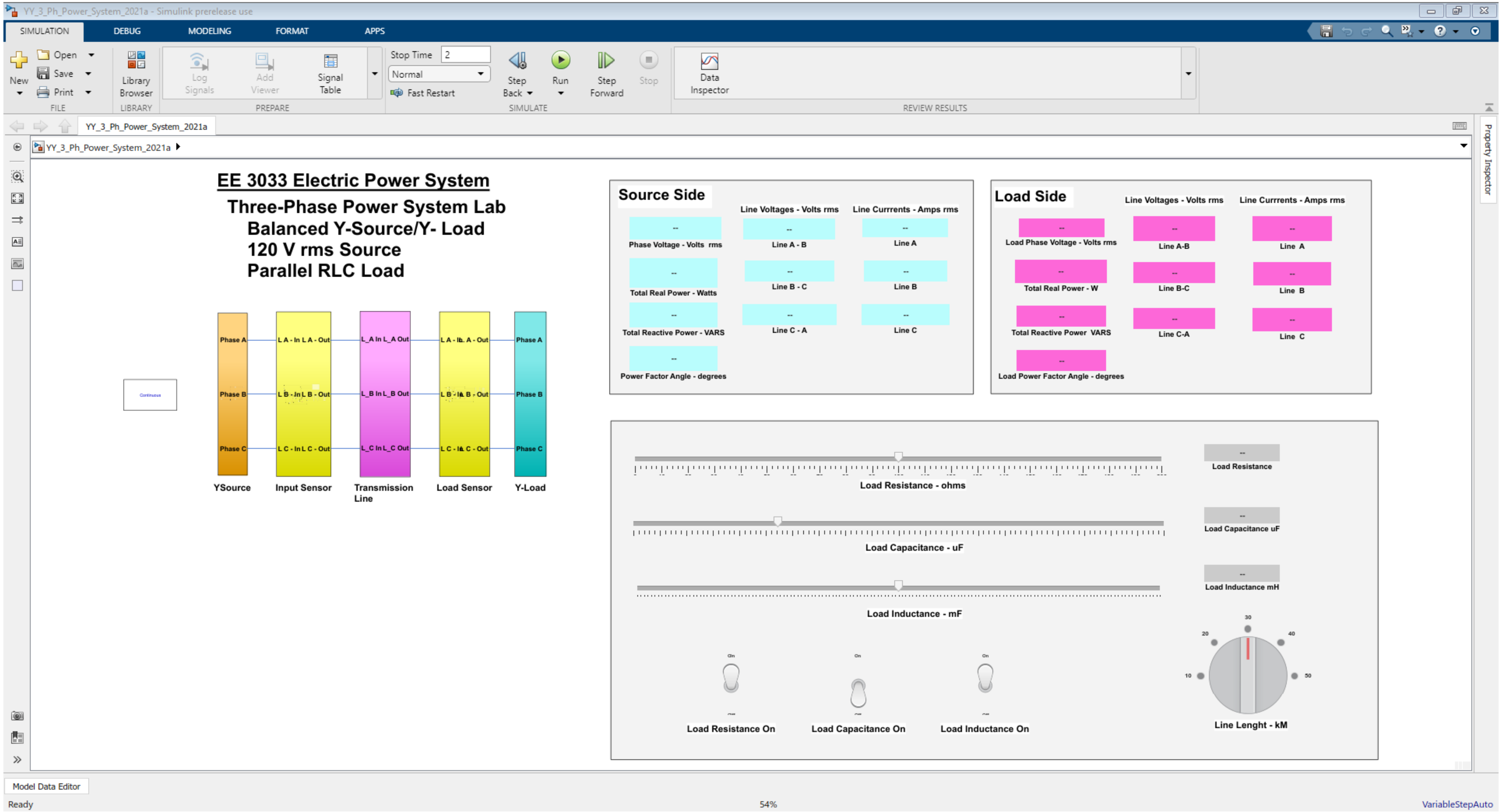
DC Shunt Motor

- **Control Panel:** adjusts the terminal voltage and applied mechanical torque, displays load, armature and field currents, load and induced torques, terminal voltage, powers, and electrical losses

Synchronous Generator

- **Control Panel:** adjust the generator speed and field voltage, displays the generator speed, induce torque, output real and reactive powers, power factor angle, and electric frequency

Simulink / Simscape: Three-Phase Power System Lab Demonstration



Student Feedback – Comparing Virtual Lab to Hardware Lab

How did you feel about using virtual labs with Simulink? Did you have a preference compared to hardware?

The student feedback was:

- ***I really hate labs because I find them very tedious**, but I think doing them in Simulink made them a lot more tolerable -- **it (the virtual labs) was slightly less tedious***

- ***I liked using the virtual labs**. I feel it was equally helpful in learning the material as using hardware. I think using hardware is more enjoyable at times because it feels more hands-on, however**, the simulated labs were less stressful**. **Hardware also allows for troubleshooting opportunities, which was not available for simulated labs**.*

- ***The simulations were a great opportunity to test a wide range of values that would normally be constricted in a lab setting**. Simulations avoid safety risks and device constraints.*

- ***Hardware provides technical experience and produces visual results, while Simulation provides an efficient way to observe large data sets and trends from a system.** Overall, I believe that using both hardware and simulation for a lab would be most beneficial.*

Student Feedback: Virtual Lab Benefits

Are there any benefits that you can say you saw using a virtual lab over a physical one?

The student feedback was:

- ***The worst part of in person labs is setting up the circuits, but that's something we need to be able to learn and do****. But I think the Simulink/Virtual labs are a lot more beneficial for a student's understanding and learning a concept.*

- *In my opinion,* ***virtual labs allowed us to see what would happen theoretically in reality****; however, I am a proponent of physical labs, where one can easily interact and understand the material more comprehensively.*

- *So, I guess what I'm saying is* ***I definitely prefer Simulink/Virtual labs for trying to understand the theory behind things****, because I think they're easier to collect and analyze data. However, I also think that* ***doing physical labs, in order to understand how to use the hardware, is just as necessary.*** *Simulink labs would be a very useful addition to any lab class, if added in the right way.*

Benefit of Virtual Labs

Student Benefits

- Gave students a feel for theory/concepts via interactive controls to understand their behavior in real-time
- Labs available 24/7 – better match to student schedule
- Improve their comfort level and confidence by working with the virtual lab

University Benefits

- Lower lab costs – no lab maintenance – no more equipment cost – no lab assistant
- Easier to stay current with technology
- Allow for virtual locations
- Address changing student populations and demographics -- changing student background experience – available for a wider student audience

Future Employer Benefits

- Experienced in the virtual engineering environment and model-based design

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Next Steps in Evolving the Virtual Labs

Next Step - Now

- Revise labs to address the student feedback – more visual – build the circuit

- Develop more virtual power labs
  - Three-phase transformer
  - DC Series and Induction motor
  - Paralleling generators

- Introduce versions of the models into the classroom

Next Step - Future

- Expand virtual lab to other topics
  - Power electronics / RF/microwave / Circuits

- Future – virtual reality??

Virtual Power Lab Revisions

Universal Control / Display Panel
- Switches, sliders, and knobs to control the lab
- Displays for the performance data
- Interactive scope

Build the Circuit
- The student builds the circuit using the lab assignment schematic and the "Library Browser“

Add Warnings
- “You let out the magic smoke”

Real Time /Continuous
- Circuit performance is updated as changes are made
- Allow the student to "watch" the circuit

Integrating Power Lab Models into the classroom

Classroom lecture

- Introduces Theory/Concepts/Equations
- Work problems

Work Problems using MATLAB/Simulink

- Use versions of lab models revised for the classroom

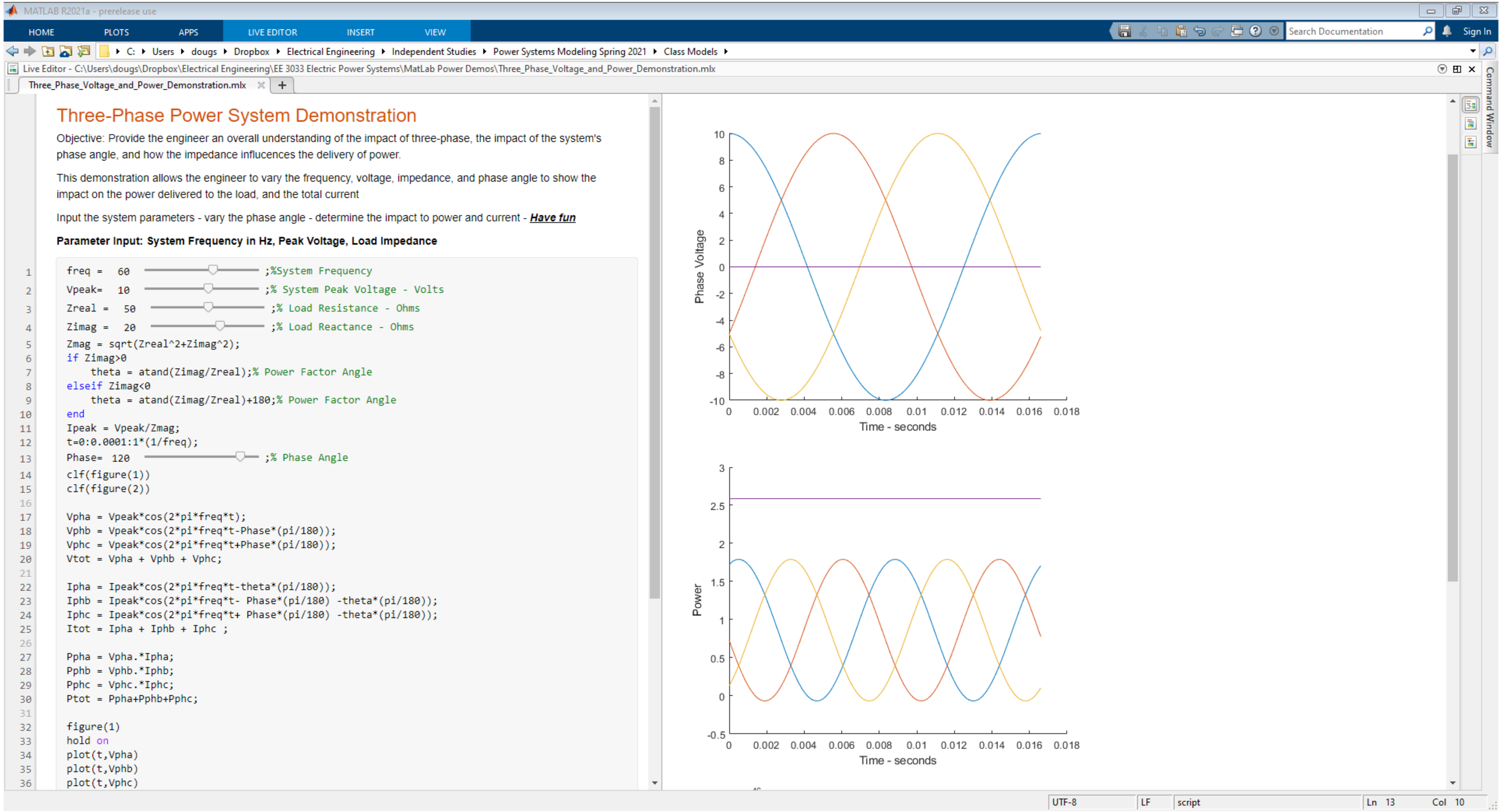
Flipped classroom allows students to “run” problems

- Explore bounds of the problems
- Summarize active results – this is invaluable – get engineering students to communicate

Guiding Design Philosophy: Learn in an Interactive and Visual Way

- Interactive control of the problem’s parameters - Real time display of numbers and graphs

Three-Phase Power System Demonstration – Extending the use of MATLAB/Simulink



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Summary

Students liked the virtual labs

- Reinforced what is taught in the classroom
- Available 24/7 which supports the student's schedule
- Provided insight to the classroom concepts

ECE Department liked the virtual labs

- Meet university's CONVID restrictions and the course requirements
- No lab equipment breakdowns
- No lab assistant required

But did not provide the complete hardware lab experience

- Needs to evolve the labs to gain the hardware experience

Virtual labs are here to stay – virtual engineering environment is here to stay

Acknowledgements

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