Preparing Students for Careers in Power Electronics

Mounzer Saleh

Academic Field Engineer

Undergraduate courses often only **model** energy conversion

.

Projects: Project I: Modeling and Analysis of Dc-Dc Converters (5% of the overall mark)
Project II: Modeling and Analysis of a 3-phase Inverter (5% of the overall mark)
Project III: To Be Announced Later (5% of overall mark)

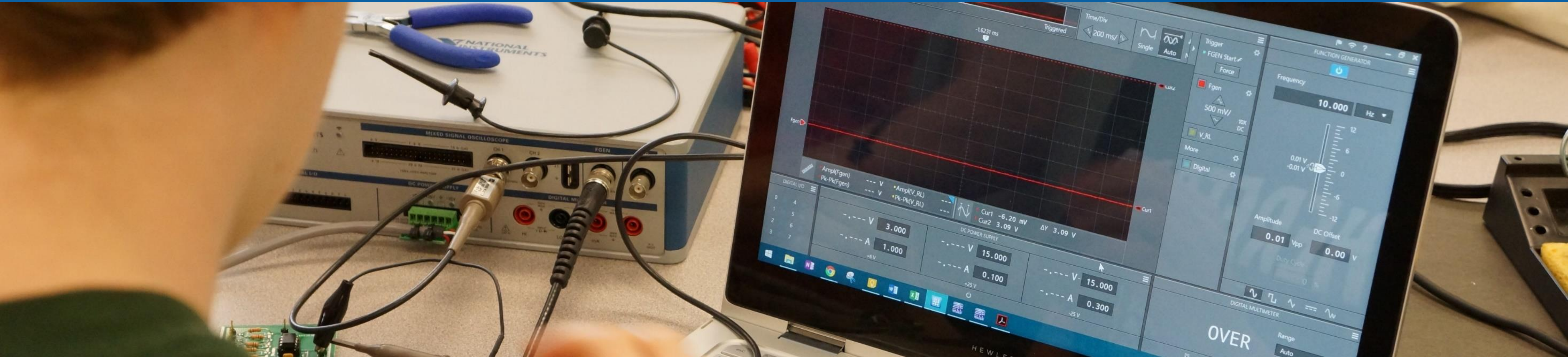
Students will be assigned with class projects to simulate the models of wind/solar generation in Simulink or run commercialized optimization software to examine impacts of wind/solar generation over the grid and their economic value.

fundamentals, synchronous generator from a magnetic field point of view, synchronous motors and condensers induction motors, DC machinery fundamentals, DC motors, single phase motors. Matlab/Simulink will be used.

Module summary

This module covers fundamentals of power system modelling, analysis and operation. The contents are deepened through lab exercises employing DIgSILENT PowerFactory.

NATIONAL INSTRUMENTS



Challenges

- Power electronics often begins with math, memorization, and lecture not engaging students
- Continuity in hardware and software is infrequently preserved between undergrad, graduate, and research
- There is a significant gap in power electronics controls education in undergraduate courses

Power electronics often begins with math, memorization, and lecture; not engaging students

Practicum/laboratory experience is **instrumental** in graduates' professional development

Only **46.15%** of universities* offer lab-oriented courses in power electronics

-Misoc, F., & Wagner, J. (2012, June), *An Overview of Existing Power Electronics Courses* Paper presented at 2012 ASEE Annual Conference & Exposition, San Antonio, Texas. https://peer.asee.org/20760

* Study made among US Universities

Continuity in hardware and software is infrequently preserved between undergrad, graduate, and research

ABET

BE CONFIDENT™

ABET Student Outcome K:

An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

There is a significant gap in power electronics controls education in undergraduate courses

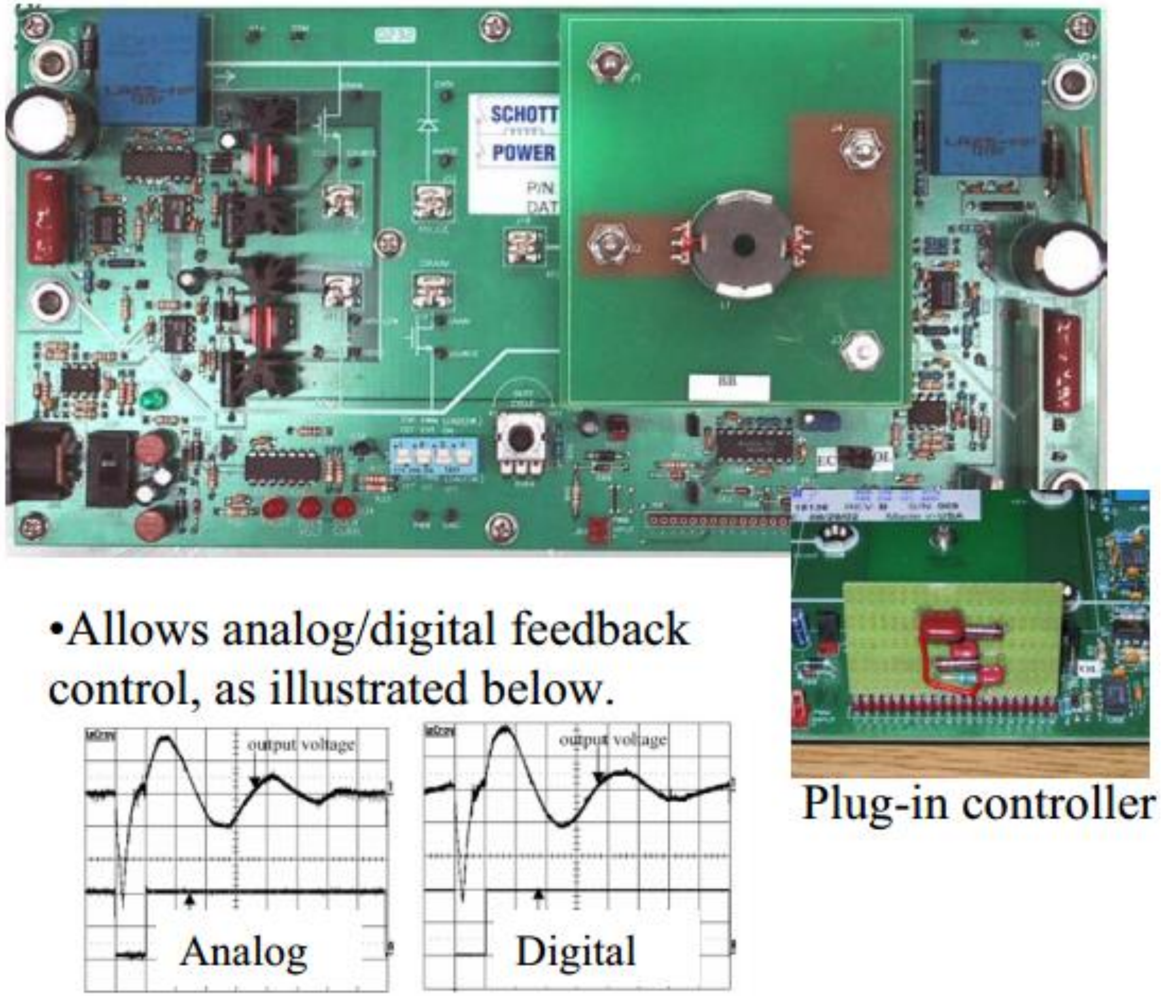
- Centralized large facilities are being replaced by millions of widely dispersed renewable power plants that require inverter to interface with the local grid.
- Grid-Derived Voltage Fluctuations are created when renewables are generating insufficient voltage to inject into the grid.
- Adequate inverter control techniques need to be in place to correct for these fluctuations by injecting and drawing reactive power when necessary while simultaneously not interfering with islanding detection

Qing-Chang Zhong
World-leading multidisciplinary expert in control, power electronics and power systems

S. Yasmeena, G. Tulasiram Das. A Review of Technical Issues for Grid Connected Renewable Energy Sources. International Journal of Energy and Power Engineering. Special Issue: Energy Systems and Developments. Vol. 4, No. 5-1, 2015, pp. 22-32. doi: 10.11648/j.ijepe.s.2015040501.14

A number of universities have implemented labs and control

- [CUSP]



But these often offer only fixed controller personalities or offer reduced visibility into algorithm behavior

NATIONAL INSTRUMENTS

The University of Manchester

Basic Circuits

Machines, Drives and Power Electronics
Single-phase transformers
Induction machines
Synchronous Machines
DC-DC
AC-DC

Generation and Transportation of Electrical Energy
Phasors/Reactive power
Components in substation
Power transformers
Synchronous generators
Power flow
Symmetrical faults

Undergraduate

Power Electronics
Single and three phase inverters
PWM voltage control
Current control
Inverter as active rectifier
Tuned PI controllers
Components
Flyback and forward converters
Multi-pulse rectifiers

Power Systems
Power flow analysis
Power system control
Asymmetrical faults
Power system stability
Economic dispatch

Advanced Power Electr
Switch averaging and sm
Three-phase power conv
Modelling and control of 3

Graduate

NATIONAL INSTRUMENTS

Basic Circuits

Transmission

UNIVERSITY OF MINNESOTA

Driven to Discover[SM]

Energy conversion and storage
Grid, energy storage, energy conversion

Intro to Power System Analysis
AC power
Large power networks
Analysis ad simulation

Undergraduate

Power Electronics
Switched Mode
Inverters
Utility system
Components

Electric Drives in Sustainable Energy
Wind and inertial energy generation
D-Q axis, vector torque controlled motors

Power Generation Operation and Control
Optimal power flow, scheduling resources, loss analysis

Graduate

Power systems engineering
Analysis of large systems
Monte carlo analysis, protection, fault isolation

Advanced Power Electronics
Advanced topology

NATIONAL INSTRUMENTS™

Basic Circuits

Power Electronics
Switching converters
Components
Harmonic distortion
Dc-ac conversion basics
Bidirectional complex power transfer

Power Systems Analysis
3-phase circuits
Generator models
Steady-state power flow
Transient stability

Undergraduate

Power Electronics Converter Topologies
Ac-dc
Dc-dc
Dc-ac
Ac-ac
Efficiency, components, modeling

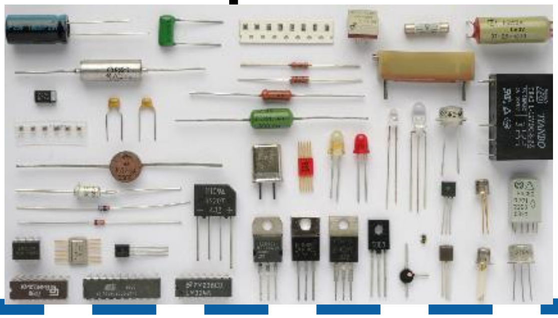
Power Electronics
SMPS efficiency
Components
Non-ideal converters
Thermal design
Closed loop dc-dc control

Graduate

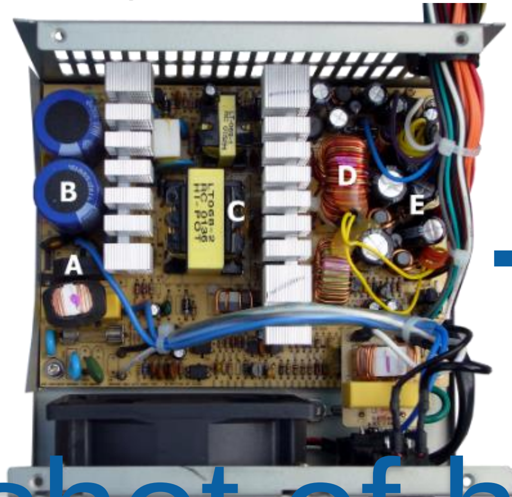
A snapshot of how power electronics is taught today

Undergraduate

Components



Energy Conversion



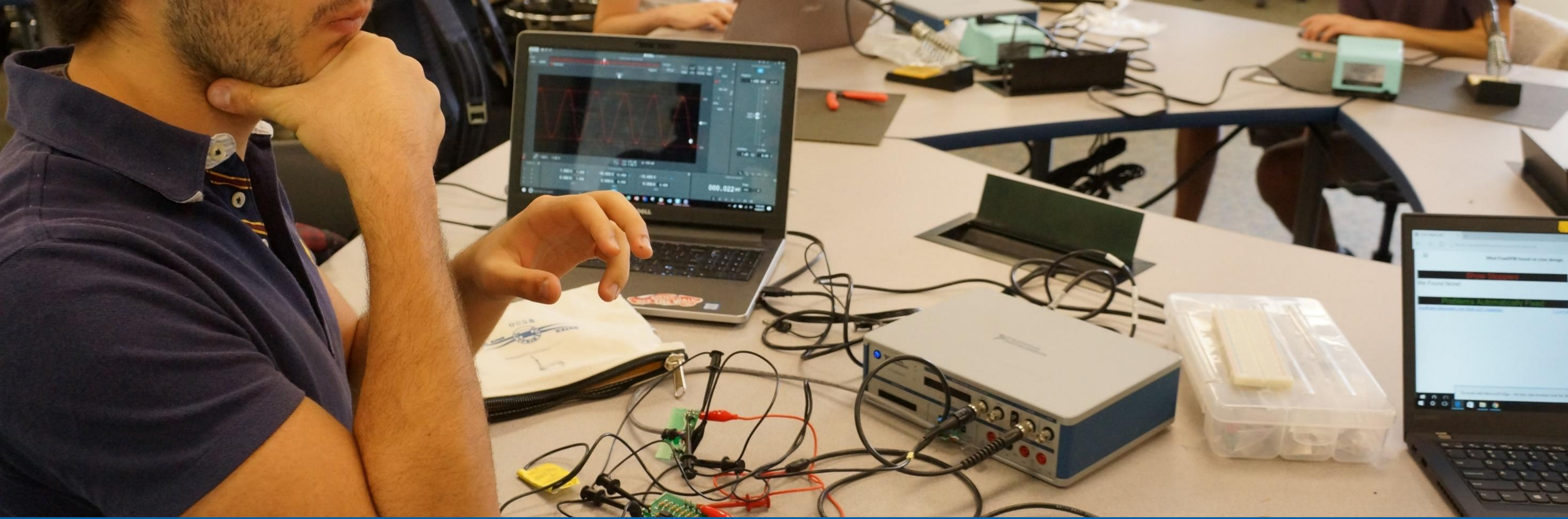
Algorithms
AND
Circuit Design

Graduate

Advanced algorithms
AND
Complete System Simulation

Research/Industry

NATIONAL INSTRUMENTS™



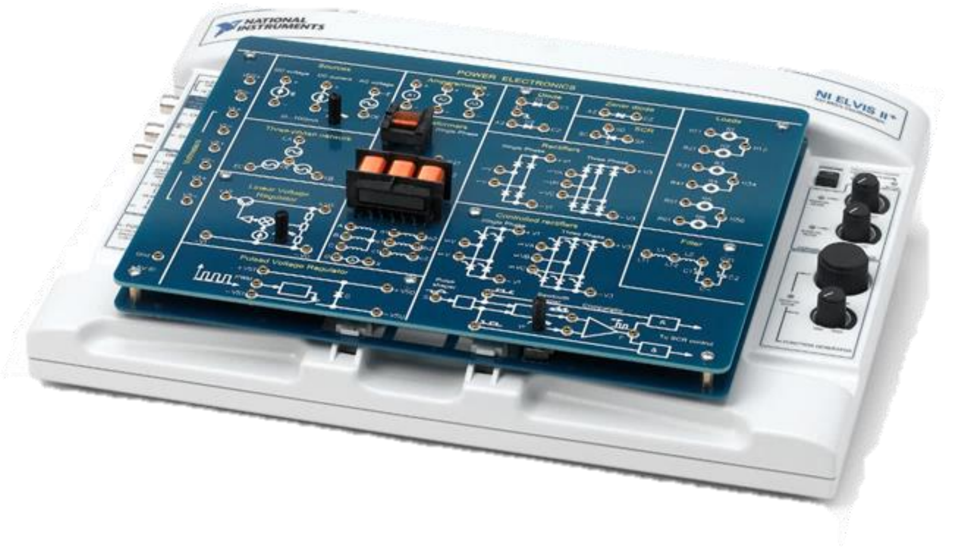
How can we teach power electronics in undergraduate programs to prepare students for these challenges?

Approach to addressing challenges

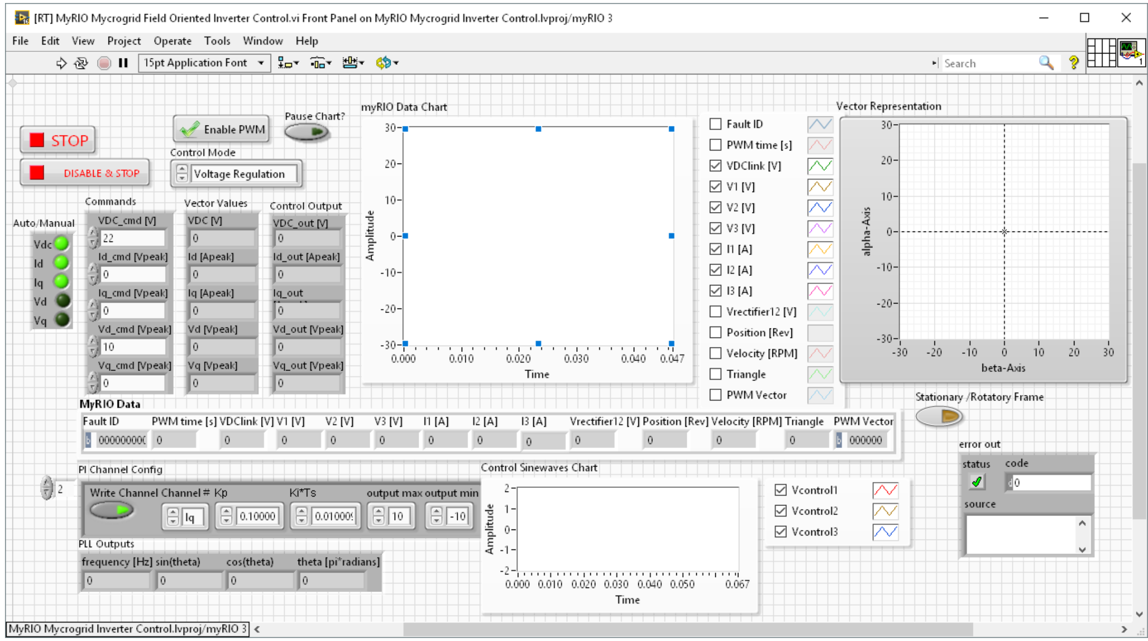
- Teach concepts with hardware from day 1
- Develop control algorithms with confidence with full simulation
- Spend equal time in deployment and simulation
- Deploy to industry proven embedded control systems
- Create your own custom control chip using reconfigurable FPGA
- Test with low-voltage first, creating a minimum viable product

	Begins with math, memorization, and lecture	Continuity in hardware and software is not preserved	Controls not addressed in undergraduate courses
Teach concepts with hardware from day 1	✓		
Develop control algorithms with confidence with full simulation			✓
Spend equal time in deployment and simulation	✓		✓
Deploy to industry proven embedded control systems	✓	✓	
Create your own custom control chip using reconfigurable FPGA		✓	✓
Test with low-voltage first, creating a minimum viable product	✓	✓	✓

Teach Hardware Concepts from Day 1



- Relate each theoretical concept to hands-on experiments
- Utilize resources:
  - NI course content on **ni.com/teach**
- Being able to demonstrate what students are working towards goes a long way
  - Example: allow students initially to play with a pre-assembled microgrid, modifying the PWM frequency and PI controller to get a feel for tuning



Integrator Power Electronics Lab

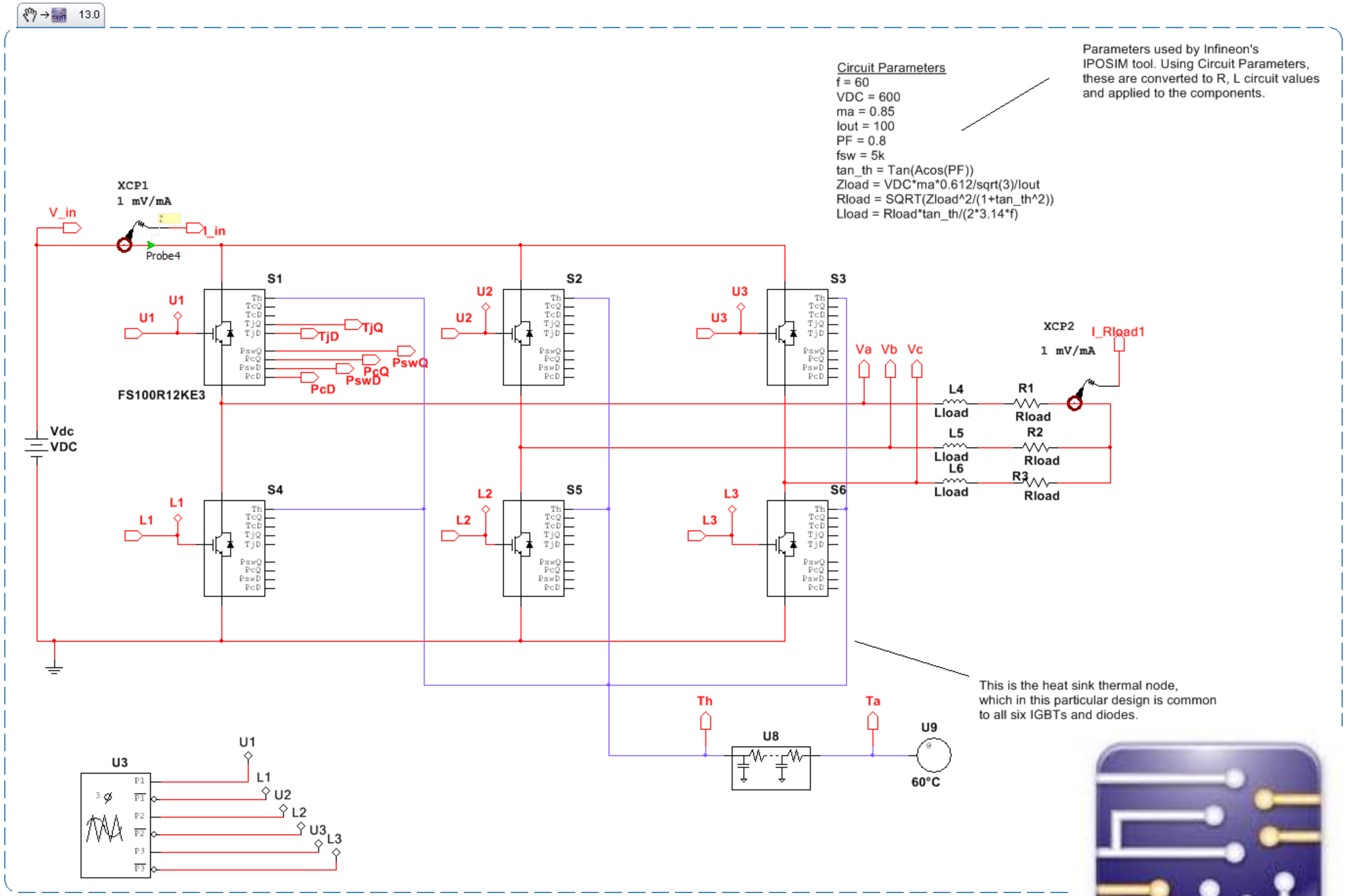
- The NI ELVIS with Integrator Power lab teaches Power electronics at a component level: laying out all necessary components for easy probing and experimenting.
- Hardware
  - All components are built into the board making the labs quick, clear, and inexpensive: without the need to find and re-purchase components each semester
- Software
  - Courseware is fully interactive with instructions built into the software and measurements automatically collated into an Excel format which is then graded without any confusion

Quanser Energy Conversion Board

- The QNET Energy Conversion board teaches a system and algorithm based power course. The real time operating system and FPGA can be programmed to precisely control the included energy conversion components.
- Hardware
  - The QNET Energy Conversion board takes a large, expensive lab setup and compresses it down to a manageable platform.
- Software
  - Students used LabVIEW in previous courses to program the NI ELVIS and now they build on that – using LabVIEW to program the real time OS and FPGA.

Develop Control Algorithms with Full Simulation

- Be able to develop circuits in simulation then exercise that circuit in a control algorithm simulation
- Simulators allow for the same design to be used from beginner to advanced analysis
  - Allowing PCB creation for deployment verification



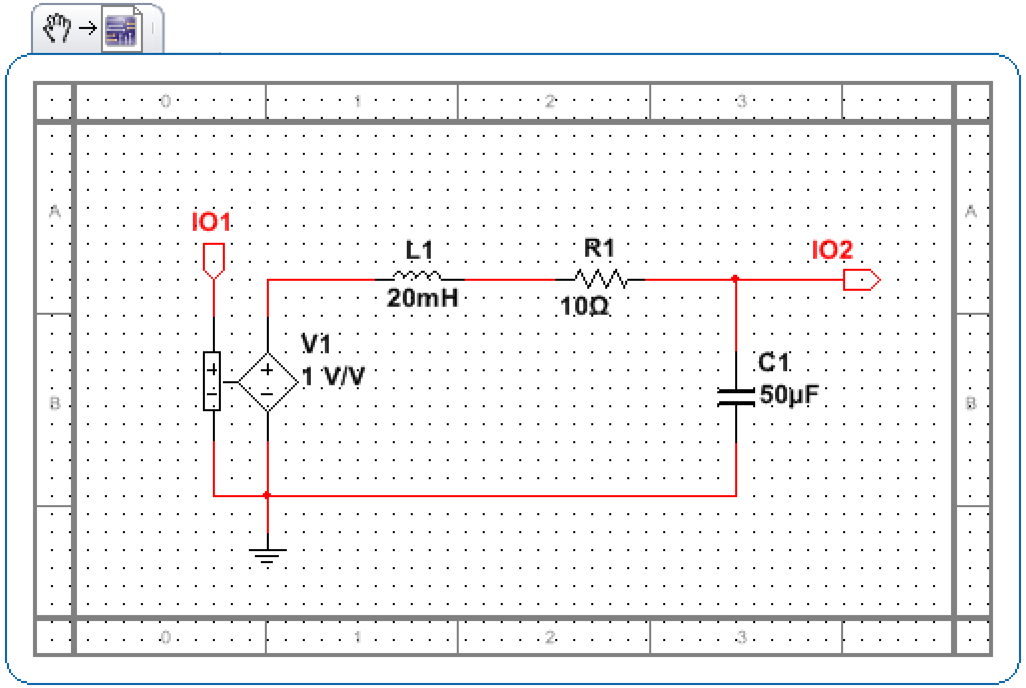
Develop Control Algorithms with Full Simulation

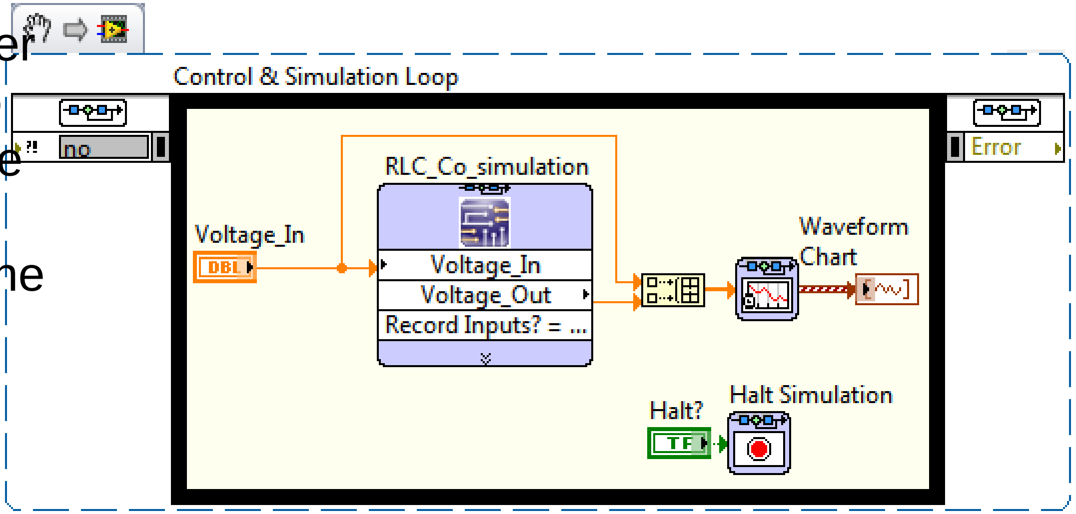
- Control algorithms developed in LabVIEW can directly control a Multisim circuit design with synchronized variable timesteps

- Enable simulation with simple and quick modification to both control algorithms and circuit designs

- “The main value of doing a cosimulation between LabVIEW and Multisim is you can create a great simulation of the power electronic stage and you can connect the control system. So you can validate the theory of the control system and validate the theory of the power electronics and you can disconnect this block from the simulation, connect a real one, then run the same code. You can save a lot of time.”

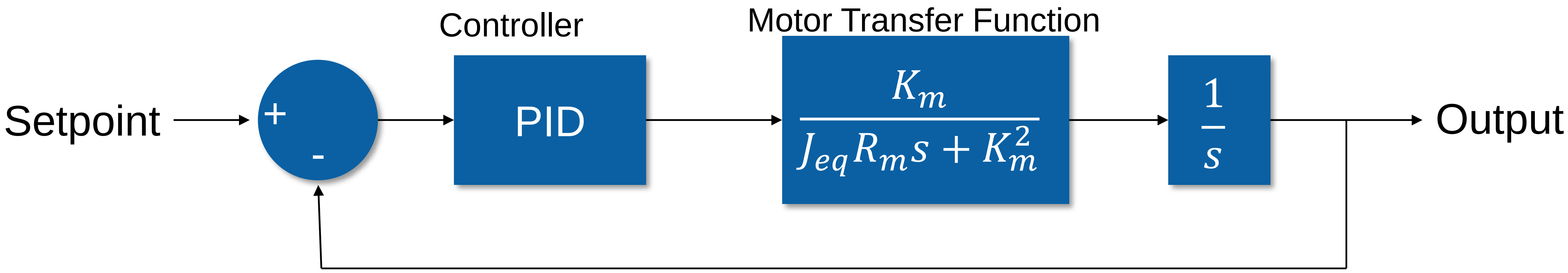
  -Pedro Ponce Technologica de Monerrey

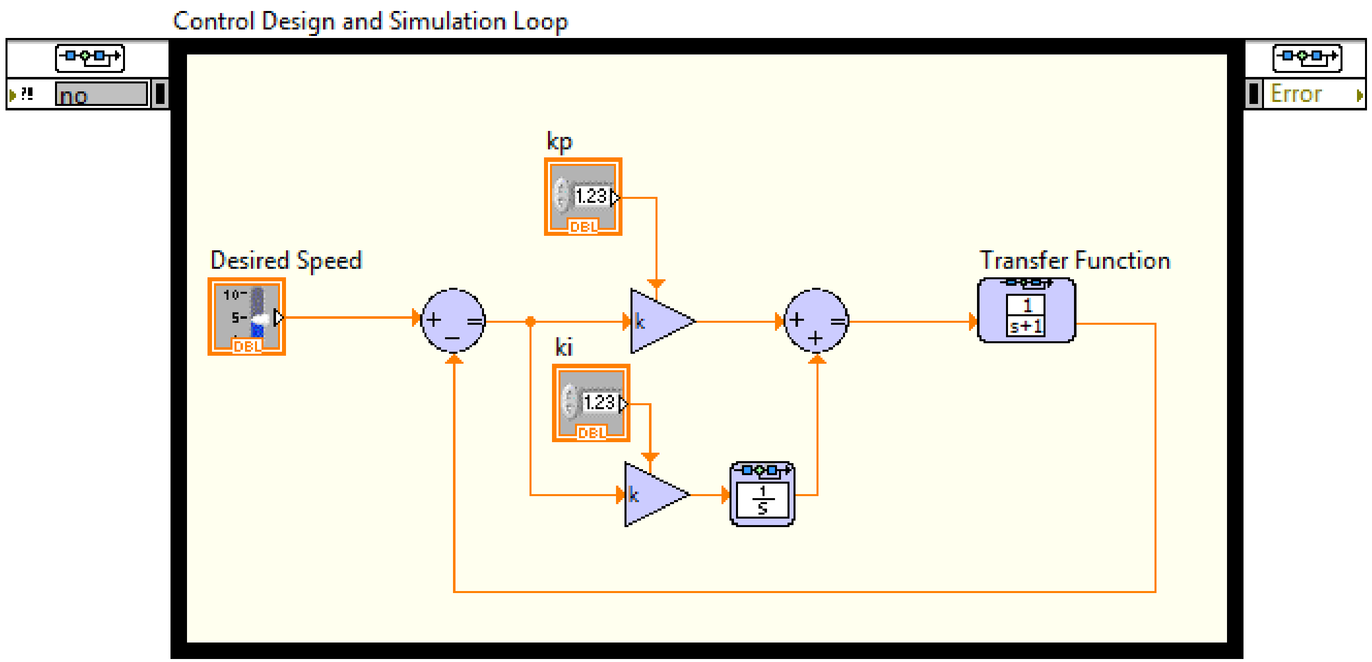




NATIONAL INSTRUMENTS

Develop Control Algorithms with Full Simulation



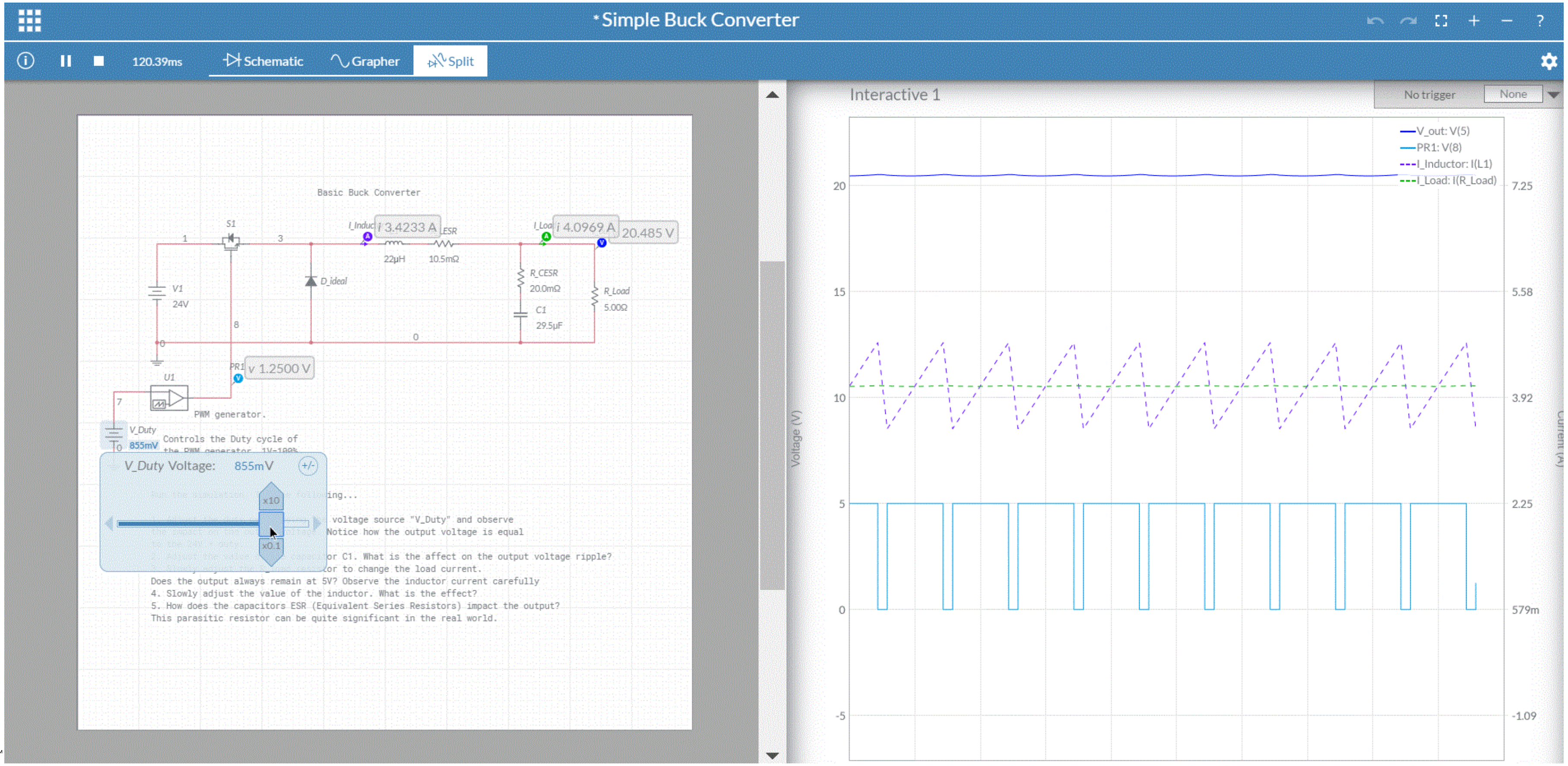


NATIONAL INSTRUMENTS

Multisim Live

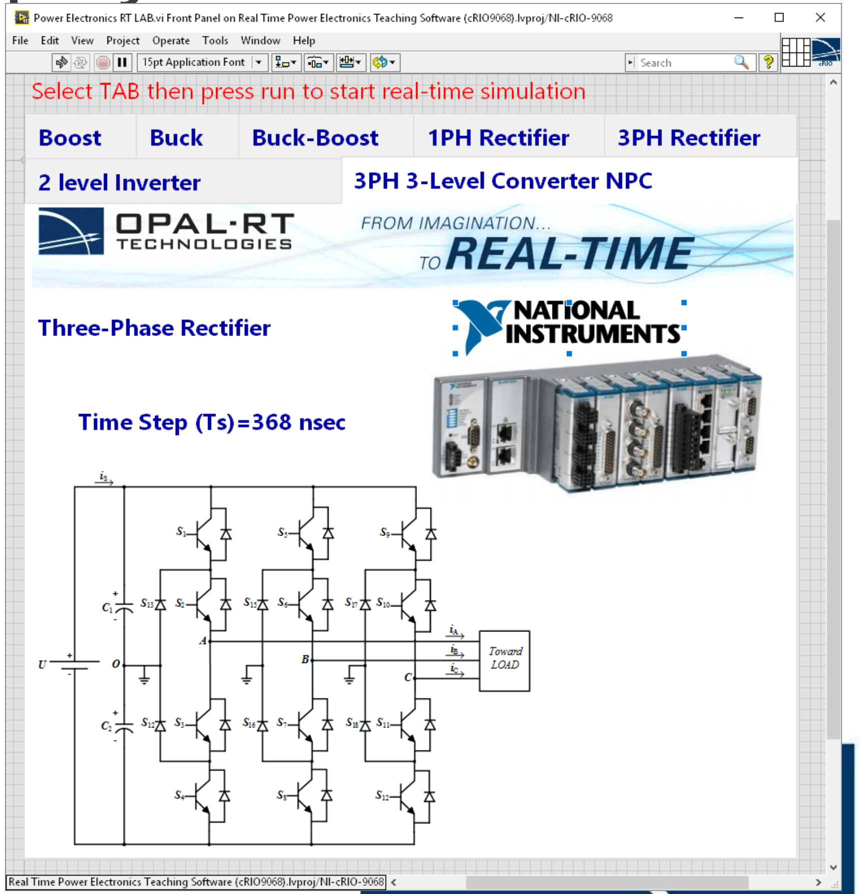
Demonstrate concepts interactively online in class or on student mobile devices

Multisim.com



Spend Equal Time in Simulation and Deployment

- Develop hands-on understanding of simulation deployed to real system with real inefficiencies
- Bridge the simulation to deployment gap with hardware in the loop (HIL)
  - Course content from OPAL-RT allows Multisim circuit to deploy to FPGA on cRIO then implements control algorithm in FPGA of myRIO

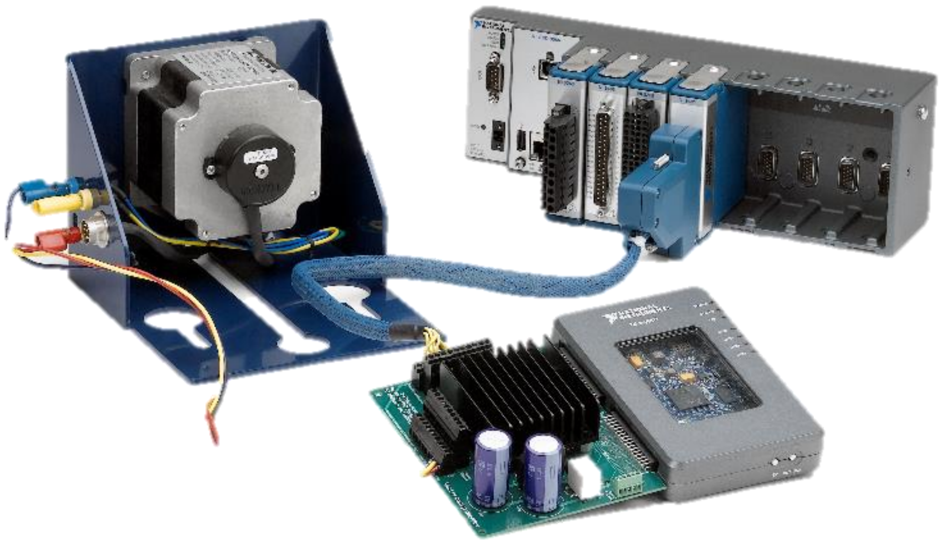


OPAL·RT

NATIONAL INSTRUMENTS

Deploy to Industry Proven Embedded Control Systems

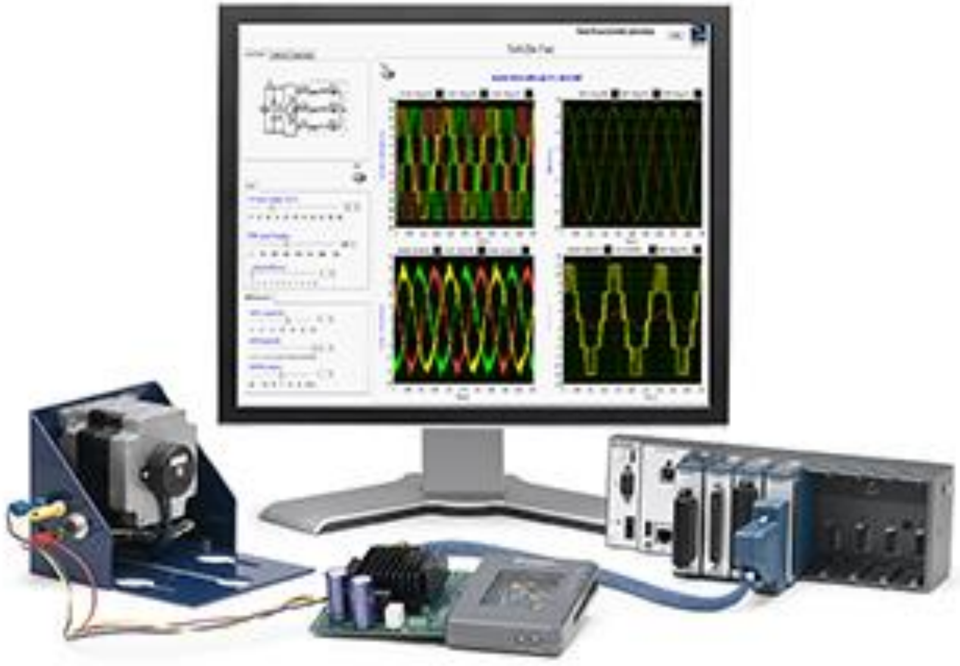
- Following cutting-edge industry trends prepares students for a career
- Reliable embedded controls systems provide reusable testbed for power electronics designs from simulation through high voltage deployment
  - Continuity of systems means one project in Energy Conversion can be built upon for the solar inverter control course



Power Electronics HIL Teaching Laboratory

Power Electronics HIL Teaching Laboratory by OPAL-RT TECHNOLOGIES is an educational courseware intended to teach power electronics to university undergraduate students

- Teach complex power electronics concepts with the inherent safety and low cost of a simulated plant
- Experiment with converters, rectifiers, and inverters along with their control techniques
- Use expert-designed lab manuals and courseware from industry leader OPAL-RT
- Learn common control and validation concepts using industry-standard HIL and RCP tools



Create Custom Control Chip Using Reconfigurable FPGA

- Reconfigurable FPGA enables fast turn-around of control algorithm design
- LabVIEW FPGA implements pseudo-code style language on a real FPGA
  - Does not require CS degree to develop and test algorithms
- Real-time data and deployment feedback allow unprecedented insight into real, running control system

Test with Low-Voltage Creating Minimum Viable Product

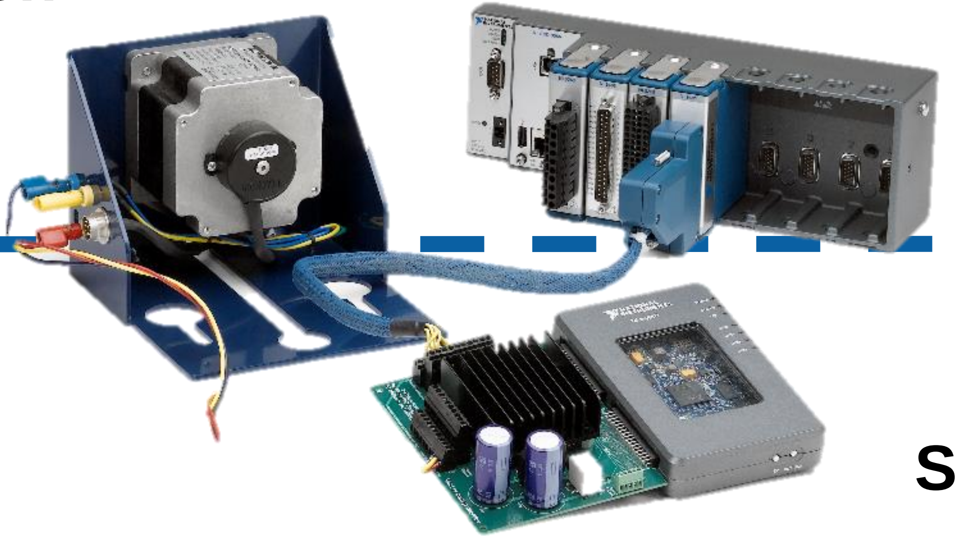
- High voltage systems add time, cost, complexity, and unnecessary danger
  - Avoid issues associated with these systems by prototyping and doing initial testing on low-voltage systems
- Low voltage system model identical behavior to similar high-voltage systems
  - Able to really test deployed algorithms in near real-life scenarios
- Transition to high voltage only when component selection, high voltage inefficiencies are key to the course

Undergraduate

Components
Integrator Power Electronics Lab

Energy Conversion
Quanser Energy Conversion Board

Real Algorithm, Circuit Design
myRIO 3-Phase Inverter Board



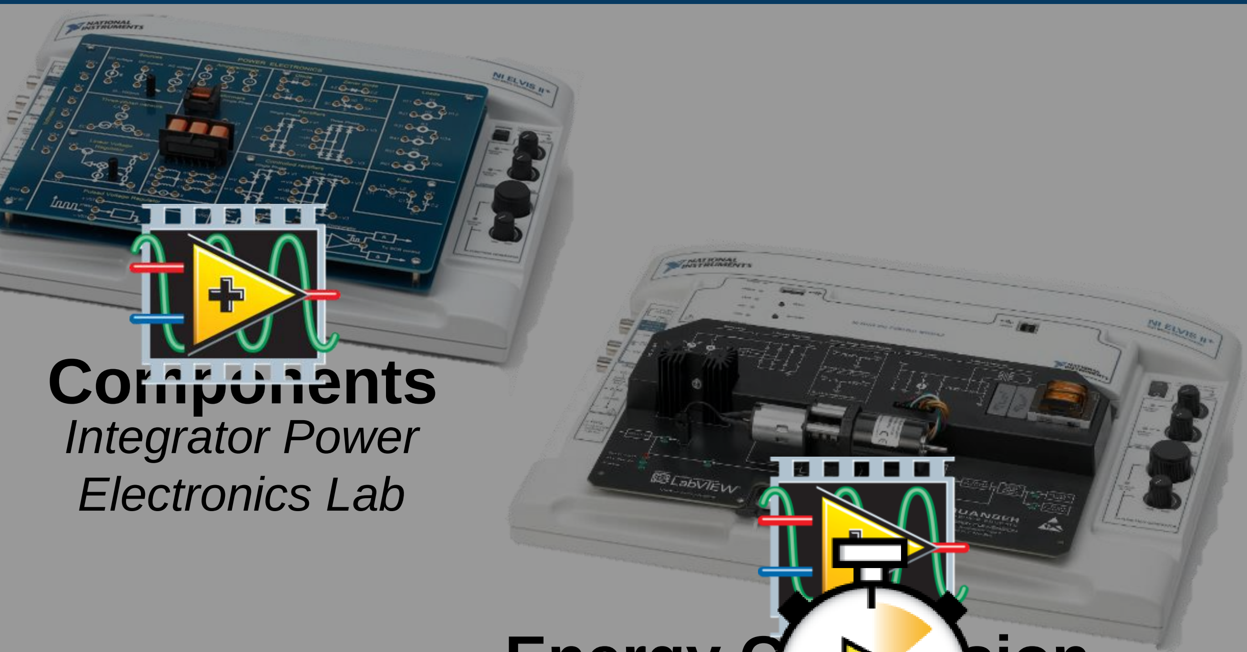
OPAL-RT

Simulated Algorithm, Circuit Design
Opal-RT Power Training Course

Graduate

NATIONAL INSTRUMENTS

Undergraduate

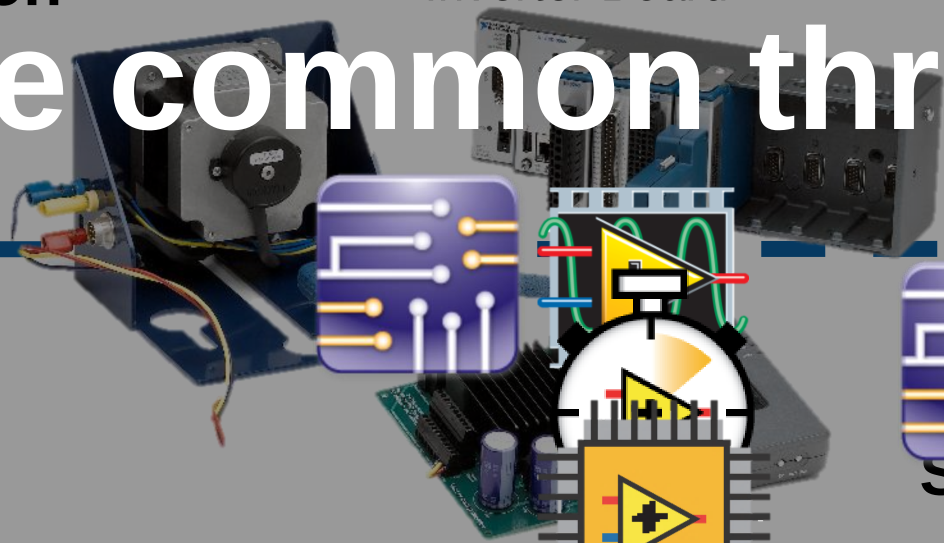


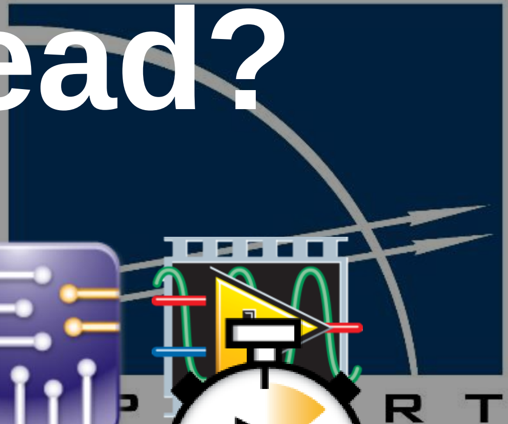
Components
Integrator Power Electronics Lab

Energy C… sion
Quanse… y
…nversion Board

Real Algorithm, Circuit Design
myRIO 3-Phase Inverter Board

What is the common thread?



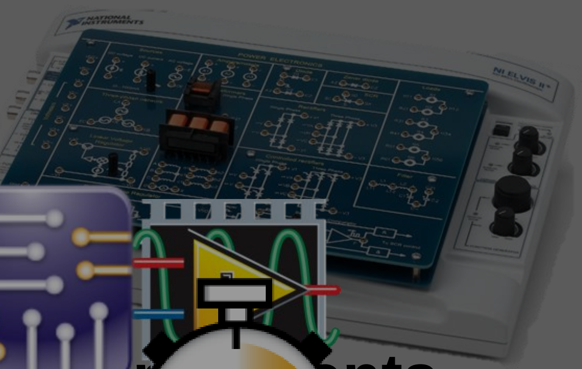


Simulat… orithm
Circ… ign
Op… ver
Traini… ourse

Graduate

NATIONAL INSTRUMENTS

Undergraduate



Real Algorithm, Circuit Design
myRIO 3-Phase Inverter Board

Graduate

In the end, continuity from undergrad to industry is key to a student's success

NI’s Aim in Power Electronics

- Make sure a student’s first introduction to power electronics isn’t equations.
- Give the opportunity to be hands-on in every single class.
- Deliver solutions to professors without the time or resources to develop a course from scratch
- Prepare students for future problems with the tools they will use after college

Mounzer.saleh@ni.com

https://www.multisim.com/

NI ELVIS Power Electronics

NREL Case Study

Oak Ridge National Labs Case Study