Is Real-Time Digital Simulation Education ready for the Classroom?
An Australian perspective

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The Education Aspect
Crossroads in Tertiary Education

Digital Transformation of Education

• Technology-enhanced learning and teaching.
• Online resources (24/7 accessible - mobile).
• Enhanced student experience and personalized learning.
• Better utilizing face-to-face hours.
• Developing and applying skills in practice.
UNSW’s 2018 Learning and Teaching Forum

- **Being Courageous:** Exploring new approaches to improve and expand learning experiences.

- **Being Employable:** Providing authentic learning experiences for workplace readiness.

- **Being Inclusive:** Designing and developing curriculum to support inclusion.
RMIT’s 2018 Learning and Teaching Forum

- **Ready for Life and Work strategy**
  - Belonging in Learning and Teaching
  - Learning and Teaching: Every Graduate Ready
  - Talented and Motivated Workforce
  - Industry for Real in Learning and Teaching
  - Making Global Work
Power Engineering Education Needs

Driven by rapid changes in the Power Industry:
- Renewable Energy and Distributed Generation.
- Extended Network Automation.
- Smart Grids.
- Computational Intelligence.
- Data Analytics and Machine Learning

Tools and Skills for the future Electrical Engineering Graduate to meet the ever-changing needs of the Industry.
The Australian Academic Context

- 4-year Bachelor’s Degree in EE
- 5-year Bachelor’s Degree in EE with Honors year
- Double degrees (EE major + minors, e.g. Science, Economics etc)
- 5-year Bachelor’s Degree in Electrical Engineering with Honors year
- 2-year Master’s Degree in EE (coursework)
RTS and the Industry of Tomorrow

Real-time Digital Simulations are becoming more common and a lot more “acceptable” in both Industry and in Research.

- Multi-physics Real-time simulations
- Interdisciplinary Topics

Real-time Digital Simulators are becoming more affordable and dedicated RTS Laboratories more widespread.
Educational Context

- Development of real-time digital simulation covers a broad range of topics across the Electrical Engineering Curriculum.

- It requires and brings together prior student knowledge in a direct and hands-on manner.
Introducing Real-time Simulations at Universities
Supporting Research Projects

- More than 60% of presentations in RT18 are from universities
- Increasing number of publications / output based on real-time simulations
- Is RTS sufficient or a step towards experimental verification?
Supporting Research Projects

- Post-doctoral Researchers,
- PhD students,
- ... some Master’s by research students.
The Gap

• For most of them, first introduction to RTS...
  • In fact, very few students [if any] will be introduced to real-time simulations in practice during previous studies.

• “Limited” exposure to off-line simulations.

• Resource intensive in large courses.
The Gap

- Filling the gap between PC-based simulation and prototype-based test-beds (specially for Power Electronics) creates a bridge that connects both sides of the software and hardware spectrum.

- Early Taste of Research: Having students interacting with RTS and control hardware will show them how a test-bed develops over time.
Our Approach
Course on “Applications of Real-time Simulations”

• Our students:
  • Postgraduate or Honors Year (5th year +) students

• Prerequisites:
  • Power Electronics / Advanced Power Electronics
  • Power Systems Analysis / Power Systems Protection (or equivalent courses)

• Students to solidify and build on prior knowledge
• Our aim: Research-based education
# Real-time Simulations Course

<table>
<thead>
<tr>
<th>Period</th>
<th>Lecture / Lab Topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 1</td>
<td>OH&amp;S – Operating in a Research Laboratory (IMPORTANT) Introduction to Real-time Digital Simulations and the RTS Lab at UNSW. Platforms of Real-time Digital Simulations.</td>
</tr>
<tr>
<td>Weeks 2 &amp; 3</td>
<td>The concept of “Real-Time” – Preparing and running real-time simulations Interpreting Simulation Results (CPU-level Simulation with OPAL-RT)</td>
</tr>
<tr>
<td>Weeks 4 &amp; 5</td>
<td>Power Electronics Simulations with FPGAs (OPAL-RT eHS module) Digital and Analog IOs, Loop-backs and Measurements</td>
</tr>
<tr>
<td>Weeks 6, 7 &amp; 8</td>
<td>Interfacing Simulators with External Hardware Control Hardware-in-the-Loop, Closed-loop control of Power Electronics</td>
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</table>
## Real-time Simulations Course

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<th>Lecture / Lab Topics</th>
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<tbody>
<tr>
<td>Weeks 9 &amp; 10</td>
<td>Power System Components – Modelling of Power Systems</td>
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<td>Differences between Power Electronics and Power Systems RTS</td>
</tr>
<tr>
<td>Weeks 11, 12 &amp; 13</td>
<td>Connection to external devices – Power Amplifiers for Protection Testing</td>
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<tr>
<td></td>
<td>Relays and Protection Hardware in the loop</td>
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<tr>
<td></td>
<td>Joint Simulation of Power Systems and Power Electronics</td>
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<tr>
<td>Other Demonstrations</td>
<td>Modular Multilevel Converters</td>
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<tr>
<td></td>
<td>HVDC Systems</td>
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<td></td>
<td>Microgrids – Modelling and Simulations</td>
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<td></td>
<td>Industry Guests</td>
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Improving the Student Experience

1. Computer-Based Simulation
   - Student
   - PC
   - Learning Outcomes

2. Full Test-Bench
   - Student
   - Control Platform
   - Hands-on Interaction
   - Delay
   - Converter
   - Learning Outcomes

3. RTS HiL
   - Student
   - Control Platform
   - Hands-on Interaction
   - HiL Platform
   - Learning Outcomes
Assessment

• Fortnightly Assessments
  • Based on the five topics covered in lecture.
  • Peer learning
  • Following IEEE article templates and requirements
  • Continuous formative assessment / feedback
  • Five Assessment Tasks (10%-15%-20%-20%-25%)

• No Written Exams
  • Oral Lab Examination (10%)

• Literature Review – Article Summary (5%)
The Student Experience
Examples of Student Work
HiL TestBed for Power Electronics

- **MAIN PC**
  - Setup & Monitoring

- **RTS PLATFORM (OPAL-RT OP4500)**
  - PWM Signals
  - Analog Measurements

- **HARDWARE CONTROLLER**

- **CONTROL FUNCTIONS**
  - DC/DC converter control
    - Open-loop
    - PI
    - MPC
    - etc
  - MPPT Algorithms
    - P&O
    - IncCond
    - Constant Voltage
    - ANNs
    - Constant Power, etc

- **OSCILLOSCOPE**
  - System Variables Measurement & Display

- **Solar Panels**
  - Analytical Models
  - Simplified Models
  - V-I Measurements

- **DC/DC Converters**
  - Boost
  - Buck/Boost
  - Flyback
  - Dual Active Bridge, etc

- **DSP (eg. TI f2837x)**
- **Arduino**
- **dSPACE ds1103/1104**
HiL TestBench for Power Electronics

The Test-Bench:
1. DSP applications development and debug console
2. RT-LAB and MATLAB control and monitoring console
3. External DSP controller
4. OP4500 simulator
5. Digital oscilloscope
HiL TestBenches for Power Electronics

The Test-Bench:
1 - OP4500 simulator
2 - Digital Oscilloscope;
3 - dSPACE ds1104 Controller Box;
4 - RT-LAB/dSPACE control and monitor console
<table>
<thead>
<tr>
<th>Learning Outcome</th>
<th>Computer-Based Simulation</th>
<th>RTS HiL</th>
<th>Full Test-Bench</th>
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<tbody>
<tr>
<td>Coding Skills</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Measuring Skills</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Hardware Skills</td>
<td>No</td>
<td>Partial</td>
<td>Yes</td>
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<table>
<thead>
<tr>
<th>Learning Environment</th>
<th>Computer-Based Simulation</th>
<th>RTS HiL</th>
<th>Full Test-Bench</th>
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<tbody>
<tr>
<td>Observation</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Interaction</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Practice</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Flexibility</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Cost</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
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<table>
<thead>
<tr>
<th>Effectiveness</th>
<th>Computer-Based Simulation</th>
<th>RTS HiL</th>
<th>Full Test-Bench</th>
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<tbody>
<tr>
<td>1 case study</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>&gt; 1 case study</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
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Challenges

- Scaling up
  - Should we? Is this for everyone?
  - Cost
  - Access to Laboratories
  - Competing Resources and Utilization against Research Projects.
Challenges

- Teaching concepts and applications; NOT tools and software.
- Topics (“what we do” vs “what is generally done”)
- Assessment
- Student background – Quality
- Should be RTS introduced earlier than final year?
THANK YOU

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