Control and Interoperability Challenges in New Energy & eMobility Systems

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New Mexico SMART Grid Center
webinar series
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Outline

An overview on my research and teaching accomplishments and outline general directions for open gaps and challenges

- **Open Gaps and Challenges**
- Research Framework and Approach
- Research Laboratory Experience
- Sample Research Projects
- Future Ambitions
“Smart Grid” Concepts: Integration of two infrastructures

Renewable sources

- Wind
- PV
- GHP
- Batt.

Thermal Power Plants

Hydro Power Plants

Renewable sources

- Wind
- PV
- Batteries

Transmission

Distribution

Integrated Information Infrastructure

- Inner Function to “Interaction” Analysis
- Bidirectional energy conversion

- Autonomous
- Communication
- Energy Management

Industry

Transportation

Commercial

Residential

More Electricity is Supplied by Electronic Sources: “Integrated”
How does power system operate with millions of power electronic converters?

Power electronics-based future grids, instead of electric machines-based, with a huge number of non-synchronous incompatible players.

How Does This Change Stability Analysis and Requirements?

more of a systems problem;
Good Solutions require whole System Thinking!
Research Framework and Approach

Electrical Energy Faces Challenges ….. But Opportunities are Bigger!

**Exponential Technologies**
- PV, Wind, Batteries, IT, Comms
- Power Electronics, Storage, Analytics

**Challenges**
- Rapid advancement in equipment manufacturing/engineering capabilities
- A lag in control system development and integration theories
- Fast control and dynamics
- Operational risks

**Disruptive Impact**
- Operations, Planning, Regulatory
- Stability, Resiliency, Cost

Forced oscillation from a wind turbine in Oklahoma
Solar Photovoltaic Event in Southern California

• August 2016:
Result of one fault: Loss of about 1200MW of solar generation

• Protection system perceived under frequency condition resulting from a distorted voltage waveform cause by the fault transients

• The inverters were programmed to cease output when f < 57Hz.

WECC: frequency dropped to 59.86 Hz for this event !!!

Ground Fault Over-voltages
Motivation: Need for grid observability and controllability

The need for real-time information on distributed energy resources to a Federal Energy Regulatory Commission panel in Washington, D.C. on Wednesday (04/11/2018):

- “The worst thing that could happen for distribution companies is to not have visibility on...that distributed energy resource”

- “We need to know the system dynamics, and how it's being operated on a real-time basis.”

This looks like a big opportunity for R&Ds and Engineering Students!
Our Approach

Learning via Building Real-time Testbeds
- "New Norm" for Education

Industry Expectations of New Engineers, Technologists
Outline

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  - Research Laboratory Experience
  - Sample Research Projects
  - Future Ambitions

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Research Framework and Approach

**Modernize the Existing Asset Base**
- Performance Improvement w/o Impacting Reliability of Service
  - Identify and Fill in Existing and Potential Gaps
  - Use Proven Tech. to Mitigate Risk
- Tool/Model Updates
- System Components & Models
- Design Basis

**V2G: Grid Support Functionality**
- Fast-Charging Static Architecture
  - $V_{grid}$
  - $i_{rec}$
  - Measurement & Scaling

- Discharging of battery energy storage to lowering the AC grid current

**Controller HIL: an effective, and fast solution**
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PV Inverter-based DERs: New Challenges

- Several of the issues that have delayed the assessment and approval of interconnection projects of distributed energy resources (DERs)
- Unique to the industry and/or unique to the types of distribution systems in operation, for example in New York State

- where instantaneous reclosing, fusing, prevalence of small hydro and other rotating generators
  - introduce safety / reliability concerns that have not been resolved
- RTS model presents a fair and accurate method for assessing these issues
- providing clear resolutions to the DER developers, utilities, etc.
Voltage Protection Scheme in Distribution Systems using RT-HIL

Utility is unable to manage PV injection locations to avoid deteriorating voltage profile.
The US Transportation Electrification Scorecard finds that California is far and away the national leader in enabling the use of EVs. (Source: The American Council for an Energy-Efficient Economy)
Architecture of typical fast-charging station

- Charging station connected to the MV distribution grid with proposed control scheme.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full-bridge cell in each module</td>
<td>2</td>
<td>DC-bus voltage</td>
<td>600V</td>
</tr>
<tr>
<td>AC voltage</td>
<td>13.8kV</td>
<td>Capacitor voltage setpoint per module</td>
<td>150V</td>
</tr>
<tr>
<td>Grid transformer</td>
<td>350kVA, 13.8kV/400V</td>
<td>DC inductor</td>
<td>1.7mH</td>
</tr>
<tr>
<td>EV battery capacity</td>
<td>450V, 20kWh</td>
<td>Sampling time</td>
<td>30 µs</td>
</tr>
<tr>
<td>DC-DC converter power</td>
<td>80kW</td>
<td>MMC arm inductance</td>
<td>3mH</td>
</tr>
<tr>
<td>Leakage inductor</td>
<td>0.22mH</td>
<td>MMC cell capacitance</td>
<td>3.3mF</td>
</tr>
</tbody>
</table>
Results with Stability Constraint

- Current imbalance condition in the AC currents of the EV Charger.
- Oscillations occurred in the common DC bus leading to unstable system.
Performance with Stability Constraints

- Common DC-bus waveform with/without Stability Loop enabling at $t=0.7$ sec.
- Distortions are appreciably eliminated without placing an excessive filters (passive) as damping element.
A Learning-based Supervisory Control Architecture

- The model is effectively trained using transfer learning algorithm and successfully validated via real-time data.
- Possibilities for future development to implement predictive algorithms with multi-step predictions.
- Integrating multiple DERs into distribution power networks that shows huge interest for the utilities and regulatory agencies.
EV Powertrains: Objectives

• A vision for the ability to combine all aspects of the drive:
  - the converter, electrical motor and control system trends

• Integrated Power Electronics Modules (IPEM)
  
  to demonstrate 10-fold improvements in quality, reliability and cost effectiveness of power electronics systems in 10 years.

• Integrated Motor Drive (IMD)

  to offer number of benefit:
  volume/mass reduction over traditional separately constructed systems

Source: Charged Electric Vehicles Magazine, Mar. 17, 2016
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Power Quality and Stability – More-Electric-Aircraft (MEA)

Replacement of some mechanical, hydraulic and pneumatic loads with electrical equivalents e.g. electro-mechanical actuators.

Motivations:
- Reduced operating costs
- Reduced fuel burn
- Reduced environmental impact

Onboard Distribution System:
Reliable, high-level of Availability, and Promptly Respond to aircraft’s operation change.

Electrical
- Avionics
- Cabin (lights, galley, in-flight entertainment etc)
- Lights, pumps, fans
- 115V, 400Hz AC

Pneumatic
- Cabin pressurisation
- Air conditioning
- Icing protection

Hydraulic
- Flight control surface actuation
- Landing gear extension/retraction and steering
- Braking
- Doors

Mechanical
- Fuel and oil pumps local to engine
Sample test results:

Long-term Stability!

Offshore Wind Power to Grid

http://mydocs.epri.com/docs/publicmeetingmaterials/1108/6XNSUMJE9MT/Siemens__-_Hild__-_HVDC_and_FACTS_make_the_Grid_Smart.pdf
Digital Twins & AI/ML Apps.

A PMU-Based Machine Learning Application for Fast Detection of Forced Oscillations from Wind Farms

- **AI/ML-Based Design, Prescriptive and Predictive Analytics**

  - **Goal:** build Machine Learning-based intelligent assistants (e.g. recommender systems) for decision support (from design to operation) considering system dynamics, uncertainties and cyber-security.

    - Exploit traditional simulation models to train ML algorithms, expanding the exploration space and deriving additional value from simulation models.

    - **Example:** wind farm oscillation detection using transfer learning and ML, with deployment at the edge.

<table>
<thead>
<tr>
<th>Model</th>
<th>Accuracy</th>
<th>False-positive</th>
<th>Missed event</th>
<th>Time for 1 prediction (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposed CNN</td>
<td>97.41%</td>
<td>2</td>
<td>6</td>
<td>0.0047</td>
</tr>
<tr>
<td>Proposed Conv1D</td>
<td>98.06%</td>
<td>0</td>
<td>6</td>
<td>0.0027</td>
</tr>
<tr>
<td>MobileNet</td>
<td>97.74%</td>
<td>2</td>
<td>5</td>
<td>0.0074</td>
</tr>
<tr>
<td>MobileNet</td>
<td>98.71%</td>
<td>0</td>
<td>4</td>
<td>0.0074</td>
</tr>
<tr>
<td>AlexNet</td>
<td>94.51%</td>
<td>12</td>
<td>5</td>
<td>0.0098</td>
</tr>
<tr>
<td>ResNet-50</td>
<td>97.42%</td>
<td>4</td>
<td>4</td>
<td>0.0174</td>
</tr>
<tr>
<td>Dense</td>
<td>94.19%</td>
<td>6</td>
<td>12</td>
<td>0.0026</td>
</tr>
<tr>
<td>Stacked LSTM</td>
<td>94.19%</td>
<td>2</td>
<td>16</td>
<td>0.0054</td>
</tr>
</tbody>
</table>

**Hardware**

<table>
<thead>
<tr>
<th>Windows PC</th>
<th>Time for 1 prediction with CNN</th>
<th>Time for 1 prediction with Conv1D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core i7 8700 – Nvidia 1080Ti</td>
<td>0.0049 sec</td>
<td>0.0022 sec</td>
</tr>
<tr>
<td>Nvidia Jetson Xavier</td>
<td>0.0357 sec</td>
<td>0.0170 sec</td>
</tr>
<tr>
<td>Raspberry Pi 3</td>
<td>0.4698 sec</td>
<td>0.0114 sec</td>
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Future Ambitions – Meeting the Challenges Ahead
In the context of USA energy goals.

All these challenges and potential solutions require new scientific & mix of experiential learning with theoretical work where Universities have a key role to support State’s goals.
Gaps and Training Orientation

• Observations:
  ✓ Gap between Training methods and Industry Needs
  ✓ In some Areas Industry is Leading the Field and vice versa, Technology Partnership for integration
  ✓ Teaching Design (Synthesis not Analysis)

• Bridge to Energy Systems
  ✓ Establish validated Models, whole System Performance
  ✓ Design with Real-Time simulation
  ✓ Multi-Domain modeling!
The Engineer of 2020*

There will be growth in areas of simulation and modeling around the creation of new engineering “structures”. **Computer-based design-build engineering ... will become the norm for most product designs**, accelerating the creation of complex structures for which multiple subsystems combine to form a final product.

In the past, steady increases in knowledge have spawned new microdisciplines within engineering (e.g., microelectronics, photonics, biomechanics). However, **contemporary challenges—from biomedical devices to complex manufacturing designs to large systems of networked devices—increasingly require a systems perspective**. Systems engineering is based on the principle that structured methodologies can be used to integrate components and technologies. The systems perspective is one that looks to achieve synergy and harmony among diverse components of a larger theme. Hence, there is a need for greater breadth so that broader requirements can be addressed. **Many believe this necessitates new ways of doing engineering.**

* National Academy of Engineering, 2004
Together...Shaping the Future of **Sustainability**

To get there, we must ...

"Bridge the Gaps"