Innovations on Power Grid Resilience at the Eversource Energy Center

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Alumni Association Distinguished Professor
Endowed Chair in Environmental Engineering
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09/12/2018 – IEEE-USA Energy Policy Committee Meeting
Eversource Energy Center

Center Leadership
Director, E. Anagnostou (CEE)
Associate Director, A. Morzillo (NRE)
Manager, M. Peña (CEE)
Eversource, Rod Kalbfleisch

Governance
10 Member Executive Committee
10 Member Advisory Board

Team
23 UConn faculty
10 Eversource managers
27 Graduate students
20+ Undergraduate students

Executive Committee
Center Leadership
Advisory Board
Coordination Team

- Forecasting:
  Astitha (CEE)

- Grid Resilience:
  Borochin (EE)

- Grid Modernization:
  Zhang (EE)

- Tree & Forest Management:
  Parent (NRE)

UConn Faculty & Eversource Managers
Graduate & Undergraduate Students • Research Collaborators
Executive Committee

UConn and Eversource Energy leadership are providing real-time insights and governance for our Center activities.
Advisory Board

Our Board’s expertise in industry, government and academia is recognized regionally and nationally for their utility, technology, policy, cyber and leadership expertise.
Affiliated UConn Faculty Members

Our Center taps the expertise of 22 faculty members across the UConn School of Business, School of Engineering, and College of Agriculture, Health and Natural Resources.
Mission & Research Goals

Delivering utility industry-relevant technologies and science-based solutions

“To be the foremost energy utility-academia partnership advancing leading-edge interdisciplinary research and technology assuring reliable power during extreme weather and security events”
Key Initiatives Overview

We are driving the innovations and advances that will create the grid of the future – intelligent, interactive, automated, safe.

- **Power Grid Storm Readiness** *1 & *2
  - High-Resolution Weather Forecasting
  - Outage Prediction Modeling (OPM)
  - Estimated Time of Restoration Modeling
  - Storm Damage Assessment Tools

- **Tree and Forest Management** *1
  - Tree Risk Mapping from LiDAR
  - Tree Biomechanics Analyses
  - Vegetation Management Best Practices
  - Community Perspectives

- **Cyber and Physical Security** *1 & *4
  - Anomaly Detection Preventing Malicious Activity in the power grid
  - Unmanned Aerial Vehicles (UAV) Surveillance systems
  - Substation Flooding Protection

- **Electric Grid Hardening** *1
  - Systems-Based Modeling to Optimize Grid Management
  - Economic Advantages of Improved Reliability and Outage Prevention
  - LiDAR Infrastructure Mapping

- **Electric Grid Modernization** *1 & *3
  - Safe Integration of Renewables
  - Optimal Storage Technologies & Distributed Generation (micro-pump-storage, CHE, batteries)
  - Forecasting PV Output
  - Grid Analytics – Forecasting loading
  - Electric Vehicles and Pricing
  - Cascading Failures from PV Systems

*1 Eversource & AVANGRID
*2 EPRI
*3 ISO-NE
*4 DoE & NSF
Power Grid
Storm Readiness
A computerized intelligence system that combines infrastructure, tree and storm characteristics to:

• predict the likely storm impact and a visualization of where outages are likely to occur.

• provide resiliency insights, such as quantifying the value of vegetation management and other network hardening investments.
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**Storm Outage Forecasting**

**Informed decision making for securing and prepositioning of crews & resources**

**March 13-14 Nor’easter**

<table>
<thead>
<tr>
<th>TERRITORY</th>
<th>ACTUAL TROUBLE SPOTS</th>
<th>PREDICTED TROUBLE SPOTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT</td>
<td>646</td>
<td>500-1000</td>
</tr>
<tr>
<td>EMA</td>
<td>4874</td>
<td>2000-3500+</td>
</tr>
<tr>
<td>WMA</td>
<td>22</td>
<td>20-40</td>
</tr>
<tr>
<td>NH</td>
<td>78</td>
<td>200-400</td>
</tr>
<tr>
<td>UI</td>
<td>360</td>
<td>120-250</td>
</tr>
</tbody>
</table>
Weather Forecast Improvements

*Improved data forcing for outage modeling.*

- **Wind speed errors** are reduced by **20-30%** in winter, using various post-processing techniques (Yang et al., *JAMC*, 2017; Yang et al., *MWR* 2018)

- Spatial and temporal errors, both **random and systematic**, are reduced substantially

![Random Error Improvement](chart.png)
Weather Forecast Improvements

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Random Error Improvement
Weather Forecast Improvements
Improved data forcing for outage modeling.

30% error reduction compared to the NCAR ensemble mean.

Gridded Bayesian Regression

Observed wind speed

Forecast Lead Time (hours)

0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 m/s
Restoration Time Estimation

Faster and cost-efficient restoration.

Agent Based Model

Storm 1

Storm 2

Storm 3

Storm 4

Storm 5
Restoration Time Estimation

Faster and cost-efficient restoration.

Agent Based Model

Average Time to Restoration

- Number of Mutual Assistance Groups
- Time to Arrival, days
- ETR, days
Tree and Forest Management
Identifying tree risk to infrastructure

Use LiDAR to identify locations where trees are capable of striking power lines.
Identifying tree risk to infrastructure
Evaluating tree risk due to environmental conditions.

A vegetation risk model to improve damage prediction and prioritizing vegetation management.
Roadside Management Program

Storm-resistant roadside trees and forests.

**Current conditions:**
Along much of the roadside in southern New England are dense woodlands of maturing trees growing under stressful conditions.

**Identify Acceptable low-risk trees:**
Within roadside stands as many healthy, robust, straight trees with balanced crowns that present little risk to power infrastructure.

**Identify and remove high-risk trees:**
There are also diseased or dying trees, or trees with visible structural defects and/or pronounced lean to the ROW, and these do present a risk to roads and wires.

**Lower density post-treatment desired condition:**
Removing undesirable trees and creating more growing space for acceptable ones encourages healthy growth and the development of more wind-firm features, creating a stand that is more resistant to storm damage.

10-15 years later: re-evaluate.
Biomechanical Assessment

Improve our understanding of the motion characteristics of trees and changes that take place after a thinning operation.

Since 2012, three study sites have been established along roadsides in Connecticut to monitor tree sway under different vegetation management conditions.

Factors Influencing Tree Sway Frequency

Tree sway frequency increases with loss of foliage, freezing temperatures and more stout tree forms.

Managing the roadside forest to foster stout tree forms has the potential to increase sway frequency and a trees’ resistance to wind throw.
Grid Vulnerability Assessment
Monitoring Utility Infrastructure

Automated line mapping from mobile LiDAR.

Preliminary algorithm developed to interpolate line locations in areas of vegetation concealment.

Algorithm results

Gap in line coverage
Monitoring Utility Infrastructure

Automated extraction of pole attributes (height, lean, diameter) from LiDAR.

<table>
<thead>
<tr>
<th>attribute</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>height (ft)</td>
<td>~ 39</td>
</tr>
<tr>
<td>lean</td>
<td>&lt;10°</td>
</tr>
<tr>
<td>Mean diameter (in)</td>
<td>~ 12</td>
</tr>
</tbody>
</table>
Monitoring Utility Infrastructure

Pole structural integrity model.

Finite element model driven by LiDAR-derived features:

- Pole lean
- Tapered pole
- Reduced cross-sections of pole:
  (a) line bundle zone
  (b) equipment attachments

Equivalent reduced cross-section by adding holes or gauges
Total System Assessment Model

Electric Grid Hardening - Systems Approach to Resilience Assessment

- Tree trimming v.s. replacing poles
- Fragility: physics-based/data-informed modeling
- 76 storm events to feed the model
- Effect of SMT and ETT to reduce outages

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Predicted Outages</th>
<th>Actual Outages</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>13874</td>
<td>15213</td>
<td>0</td>
</tr>
<tr>
<td>1% Reduction</td>
<td>12748</td>
<td>15213</td>
<td>8.12</td>
</tr>
<tr>
<td>10% Reduction</td>
<td>10256</td>
<td>15213</td>
<td>26.08</td>
</tr>
<tr>
<td>50% Reduction</td>
<td>4438</td>
<td>15213</td>
<td>68.01</td>
</tr>
</tbody>
</table>
Economic Value of Avoided Outages

Average Annual Benefits of Trimming from Outages of More than Five Minutes
Utility Resilience Investment Planning

The reduction in SAIDI for a sample of segments of the electrical network, as the budget for resilience increases

Note that similar resilience investments have varying effectiveness for reducing SAIDI on different segments.
Cyber and Physical Security
Substation Physical Security

Securing substations from potential UAV attacks.

- Evaluate commercial systems (radar, acoustic, LiDAR, optical/thermal) for detecting different types of UAVs
- Explore cost efficient and easily-implemented methods for neutralizing UAV threats:
  - Equipment or facility cages
  - Localized GPS or radio interference
  - Geofence

Substations’ Risk of Flooding
Estimating flood risk of critical power infrastructure.

Predicting floods up to three days in advance and issuing warnings when they are expected to rise above a substation’s critical level, using:

- weather forecasts
- hourly precipitation data from radar
- distributed hydrologic and hydro-dynamic models
Geomagnetic Disturbances
Understanding GMD impact on HVDC grids.

Solar wind-high energy charged particles streaming outward from the sun can affect earth’s magnetic field.

Planetary Geomagnetic Disturbance (GMD) Intensity by Solar Cycle

Sun’s magnetic polarity reverses every 11 years, solar activities follow 11 year cycle.

large geomagnetic storms generally have not occurred around the peaks of sunspot activity.
Cybersecurity for Attack-Resilient Electric and Gas Networks
A DOE CEDS Proposal Submitted by: UConn, Argonne & Brookhaven National Labs
Integration of PVs in the Power Grid

Unintentional Islanding Evaluation

A method for quantifying regions in which islanding detection schemes fail to detect the abnormal islanding mode:

- Software tool developed reduces utilities engineer’s case study time from months to just a few minutes
- Towards a pure data-driven, machine learning approach

\[
P (> 3s) = 0.024\
P (> 1s) = 0.056%\
\]
Integration of PVs in the Power Grid

*Extreme PV power analytics*

- Explore how extreme PV is related to weather parameters
- The utility service territory is divided into several clusters at a given time interval, such that PV systems homogeneous in terms of the extreme output.
Offshore wind energy
Towards real-time high-resolution modeling & observing system

Underwater Acoustic sensors

![Diagram showing ambient sound record and geophysical interpretation](image-url)
Offshore wind energy
Towards real-time high-resolution modeling & observing system

Statistics of Wind Extremes and Impact

Empirical wind distributions

Extreme wind frequency analysis and its geographical dependence.

Grid Balancing Solutions for deep penetration of intermittent renewables

**Pumped hydroelectric energy storage**


Grid Balancing Solutions for deep penetration of intermittent renewables

DOE ARPA-e Proposal led by EnviroPower LLC
Grid Balancing Solutions for deep penetration of intermittent renewables

DOE ARPA-e Proposal led by EnviroPower LLC

PEAK SHAVING

SMOOTH INTERMETTENCY

New England Hit Record-High Solar Power Output on April 9, 2018
At 2 p.m., behind-the-meter solar reduced grid demand by almost 2,300 MW.

Source: ISO New England
Annual Workshop

Three years of utility-academia partnership in tackling real-world challenges where weather, resilience and energy intersect.

THE UNIVERSITY OF CONNECTICUT CORDIALLY INVITES YOU TO ATTEND THE EVERSOURCE ENERGY CENTER’S ANNUAL MEETING.

Please join us for research updates from our faculty and students, and to meet our Center’s Advisory Board members.

DOUG DORR
PROGRAM MANAGER, ELECTRIC POWER RESEARCH INSTITUTE

KATIE SCHARF DYKES
CHAIR, CT PUBLIC UTILITIES REGULATORY AUTHORITY

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VICE PRESIDENT OF EXTERNAL AFFAIRS AND CORPORATE COMMUNICATIONS, ISO NEW ENGLAND

WILLIAM HACKETT
DEPUTY COMMISSIONER, CT DIVISION OF EMERGENCY MANAGEMENT AND HOMELAND SECURITY

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CHIEF CYBERSECURITY RISK OFFICER, STATE OF CONNECTICUT

ROB KLEE
COMMISSIONER, CT DEPT. OF ENERGY AND ENVIRONMENTAL PROTECTION

DAVID OWENS
EXECUTIVE VICE PRESIDENT (RET.), ELECTRIC EDISON INSTITUTE

PETER ROTHSTEIN
PRESIDENT, NEW ENGLAND CLEAN ENERGY COUNCIL

CHRISTINA SAMES
VP OF OPERATIONS & ENGINEERING, AMERICAN GAS ASSOCIATION

JOE THOMAS
VP OF ELECTRIC SYSTEMS OPERATIONS, UNITED ILLUMINATING/AVANGRID

NOVEMBER 9, 2018
9:00 A.M. - 1:00 P.M.
INNOVATION PARTNERSHIP BUILDING
UNIVERSITY OF CONNECTICUT

Please RSVP by Friday October 26, 2018
EversourceEnergyCenter@UConn.edu
or by calling (860) 486-3785.

Click here for directions to the Storrs campus and parking in North Garage.
Thank you!