EVERSOURCE – UCONN PARTNERSHIP RESEARCH PILLARS

Global warming is driving increasing frequency and intensity of severe weather events; this poses substantial challenges to utilities tasked with maintaining a resilient grid capable of consistently and equitably transmitting and delivering energy. Climate change affects the health, structure, and growth of vegetation that combined with severe weather events escalate their potential impacts on transmission and distribution networks.

Electricity, heat, and transportation are currently the major sources of greenhouse gas in the United States. Therefore, decarbonizing the transportation sector through electric vehicles and moving towards electric heating would shift the focus towards clean energy sources for the power industry. In light of that, regional governments, federal legislature and utility customers are attempting to mitigate the effects of climate change by shifting toward energy efficiency, renewable generation and electrification, thus increasing the importance of uninterrupted electric power and heightening the implications and costs of power outages for customers.

Customer adoption of existing and new technologies further alters the grid, adding additional dynamics where customer energy efficiency increases, while some technologies allow customers to become suppliers of their own electricity. The increasing pace of building and transportation electrification imply greater reliance of customers on electric power which puts the electric grid at the forefront of today's societal needs and increases the importance of resilient power distribution as a component of equity and justice associated with customer resources and political and socioeconomic power dynamics.

Several critical research and development plans are needed to ensure a safe and efficient grid transition to the new zero carbon era. The combination of climate change and an evolving societal relationship with electric power necessitates a significant overhaul in how the electric utility industry plans for reliability and resilience in both transmission and distribution systems while simultaneously incorporating individual consumer behavior to new technologies. The grid of the future will need to be capable of incorporating customer behavior and decision-making while integrating modern technologies in order to meet public policy and clean energy objectives. It will be characterized by cost-effective solutions by increasingly looking at distributed clean energy sources (DERs).

Our mission at the Eversource Energy Center is to investigate and assess solutions aimed at increasing the reliability and resilience of the grid, modernizing the grid through new technologies, facilitating a safe and secure deployment of DERs, and ensuring a smooth transition from traditional to renewable energy resources.

TO FULFILL OUR MISSION,

our center will focus the new EVERSOURCE-UConn partnership research activities over the next five years under the following five pillars:

1. **Grid Resilience in a Warming Climate**
2. **Grid Reliability in a Changing Demand Environment**
3. **Renewable Energy Integration**
4. **Cyber-Physical System Security**
5. **Workforce training, outreach, and policy**

PILLAR ONE: Grid Resilience during adverse weather and climate conditions

1 Given the goal of promoting development of a resilient, equitable, and climate-adapted energy system, work under this pillar will focus on:

- **Storm forecasting and restoration modeling:** To improve the predictability of weather-related threats, advances in weather forecasting, storm damage prediction (OPM), assessment (DARM), and restoration (ABM) models are needed. These models are based in part on past weather and associated outage data and will be supplemented with projected weather changes (as historical data can be misleading in the context of the rapid changes we are now seeing) to inform efficient utility Storm Preparedness, Management, and Restoration.

- **Grid resilience metrics development:** Several reliability metrics for customer outage duration and frequency exist, but no established metrics for assessing current system resilience or future resilience improvements are available. These resilience metrics are needed in order to quantitatively assess system performance, measure system vulnerabilities under High Impact Low Probability (HILP) events and evaluate the efficacy of mitigation solutions despite the highly stochastic and unrepeatable nature of HILP events.

- **Adapting vegetation management to climate change:** Climate adapted vegetation management options are needed to maximize resilience, optimize investment, and maintain the ecosystem benefits and climate mitigation potential of vegetation. Implementation scenarios need to be developed that incorporate assessments of the effects of future warming, forest health, and disturbances on the coupled forest-infrastructure system alongside spatially explicit information on system and stakeholder characteristics. As an input to vegetation management scenarios and outage prediction models we will develop new models to assess the potential effects of climate change on tree failures, based on dynamic vegetation conditions and tree failure probabilities derived from biomechanics models. The secondary impact of extreme events on the vegetation and then on the overhead conductors is also of interest in this category.

- **Climate-focused load modeling:** The shift to greater building and transportation electrification and increased DERs will result in different demand patterns that will be more directly weather dependent and thus more difficult to predict. Charging of electrified vehicles or fleets of vehicles needs to be controlled, or it can end up increasing demand, and/ or result in flat load patterns that can accelerate the loss of life of grid assets. This task aims at efficiently forecasting load peaks and load shapes based on expected climate change impacts and during specific extreme weather events. Since weather extremes (storms, droughts, heat waves) will also strongly affect energy generation and demand in the future, it will be necessary to investigate and model weather-related criticalities in the energy balance and propose grid resilience solutions that consider the impact of weather on the combined generation, transmission, distribution, and storage system.

- **N-K contingency planning:** Resilience encompasses a variety of HILP events, not just extreme weather manifestations. To this end, advanced contingency analysis techniques beyond N-1 criterion is needed to accommodate multiple scenarios caused by unusual events, such as simultaneous tripping of multiple inverter-based resources (IBRs), extreme weather events, etc.

- **Resilience standards:** Changes in current grid reliability planning studies are needed to develop new resiliency frameworks into prescriptive standards. Potential future standards may include scenarios characterized by loss of multiple stations due to flooding, entire transmission corridors due to hurricanes, or gas pipeline outages resulting in outages of combined cycle plants.

PILLAR TWO: Grid Reliability in a Changing Demand Environment

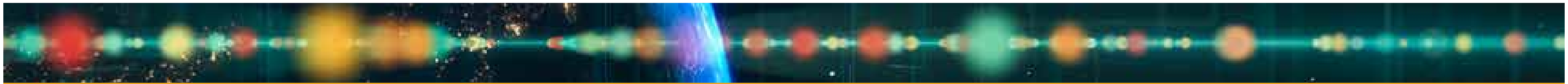
2 **Within this pillar, UConn would continue to work with Eversource on projects that bring tangible improvements to the reliability of the grid.**

- **Distribution system model quality and visibility improvement:** Develop and test methods for validating and calibrating distribution system models using real-time data (such as synchrophasor measurements, smart meters, locally available sensors, etc) in a real-world environment to support grid operations and advanced visibility tools and analytics to detect and monitor system operating conditions, security boundary, equipment health and states.
- **Frequency stability**: Identify the critical inertia level and the strength of the system to maintain frequency stability and inform proper power reserve planning, as well as placement of battery storage, and development of advanced grid forming control technologies.
- **System vulnerability assessment:** Probabilistic analysis tools to quantify the impacts of uncertain DERs and loads on system operations and identify the dominant factors that restrict system reliability, such as look-ahead probabilistic contingency analysis tools to obtain the security boundary with the forecasted errors from solar/wind/loads; tools to identify distribution system cascading failure risks in presence of unexpected disturbances (faults, loss of loads, etc), loss of DERs; distribution system voltage stability prediction tool considering high penetration of DERs; distribution system overloading and congestion risks with increased EVs.
- **Resource adequacy**: developing quantitative metrics in assessing distribution system resource adequacy, such as estimating the availability of variable resources, such as solar and wind, particularly during times of expected system stress; tools for quantifying the statistical variability of DERs and capability assessment.
- **Enable predictive capability for system reliability assessment**: Develop predictive analytics on system vulnerability assessment, resource adequacy estimation, and system strength quantification to proactively inform decision-making to benefit reliability through real-time measurements and improved models and simulations.
- **Integrated platforms for risk mitigations**: Capturing the interactions and interdependencies that allow development (and validation) of new control techniques, build strong understanding of the delicate balance between generation and load, and enable dynamic network reconfiguration driven by technical and economic objectives.

PILLAR THREE: Renewable Energy Integration

3 **This pillar aims at understanding the future impacts of very high levels of penetration of intermittent generations on power systems and developing enabling technologies to ensure reliable and resilient grid planning and operation. The main research areas are:**

- **Sensor technologies and data analytics**: Major power system outages are often caused in part by a lack of adequate situational awareness of grid conditions, as well as increasing complexity and variability in electricity generation and demand. To address them, this topic area will identify critical sensor needs and develop advanced data analytics that yield improved diagnostics, prediction, and prescription of all system variables and assets during normal and extreme-event conditions. Examples include to identify strategic locations for advanced sensor deployment maximizing benefits for system reliability and resiliency enhancement; AMI data analytics for distribution system feeder lateral quick fault identification; integrate data analytics with network modeling and reconstruction techniques to provide viable damage assessment results.
- **Distribution grid modeling, identification, and calibration**: Many engineering applications rely on accurate power flow models, such as grid planning, DER integration, carbon emission calculation, distribution system optimization, etc. This topic area aims to develop software solutions for distribution system model enhancement with sparsely placed sensors.
- **Non-wire solutions**: DERs, such as rooftop PV systems, EVs, batteries, and demand response from end-use loads offer savings for energy costs and opportunities for providing valuable flexibility services. It will not be possible to operate the power system with high levels of active DER participation without substantially increased ability to visualize their impacts on the system and predict their behavior. This technical area will develop analytics and novel control tools for DERs, such as: robust distribution system state estimation tool for system operating states visibility; BTM DER analytics to increase BTM DER visibility; probabilistic analysis tools to quantify the impacts of uncertain DERs and loads on system operations and identify the dominant factors that restrict system reliability; data enhanced DER control to deliver vital grid services and balance demand to help utilities achieve mission-critical outcomes; predictive visibility of power equipment; DER in planning and develop additional modeling capabilities for comparing the performance of DERs and traditional investments.
- **Granular renewable energy prediction**: Granular probabilistic solar, hydro and wind power forecasting ranging from minutes to week-ahead. This allows the power system to adapt more effectively to changing conditions, meeting changes in demand at optimal cost.
- **DER management for grid services**: Data enhanced DER control to deliver vital grid services and balance demand with supply to help utilities achieve mission-critical outcomes, including voltage regulation, peak demand reduction, three-phase unbalancing mitigation, network reconfiguration. This also includes smart inverter control of DERs and its coordination with legacy utility-owned devices, such as OLTCs and capacitor banks, etc.
- **Distribution system protection with high DER penetration:** This topic area seeks adaptive protection solutions that can keep the power system stable by isolating the faulted components while being able to actively change settings and functionality relative to changing system operations. The research examples can be advanced fault detection and location algorithms, specifically for difficult cases such as line-to-line faults or topology changes with varied DER fault current contributions; investigate the potential impacts to operation under frequency/voltage load shedding, or remedial-action in addition to fault-induced delayed voltage recovery; hardware and control in the loop for protection validation.



PILLAR FOUR: Cyber-Physical System Security

As the penetration of DERs significantly ramps up in New England, and our reliance on disaggregated generation increases especially with the retirement of fossil fuel generation, cyber security impacts on both the distribution and the transmission grid become critical. This research area would develop a roadmap on cybersecurity focusing on the deployment of technologies at Eversource distribution infrastructure and machine learning-based applications potentially for use within the control room to continuously monitor the state of the DERs at critical points on our grid, identify and isolate where the cyber intrusion is detected. The main research needs are summarized as follows:

- **Automated cyberattack prevention and mitigation:** Develop tools and technologies that enable energy systems to discover and address vulnerabilities (detection and prevention of ransomware attempts, at the hardware, firmware and/or software level within embedded architectures used within energy delivery control system applications), autonomously recognize a cyberattack, attempt to prevent it, and automatically isolate and eradicate it with no disruption of energy delivery. Technology with the capability to adapt and adjust to prevent future threats is desirable. The solutions should also automatically mitigate cyber-attack physical consequences that could disrupt energy delivery.
- **DER cyber security hardware and software platform:** i) develop analytical tools to study DER network vulnerabilities, impacts on system security, and tools in detecting them, such as vulnerability indices related to system reliability, stability and resiliency; ii) detection and mitigating tools: This may be achieved using the DER network patterns and physical system unique characteristics, including a reconfigurable network to isolate DER attacks (analogy to BYOS), fusion network and physical systems data and parameters for better cyberattack visibility, and resilient control and optimization against attacks. Robust deep reinforcement learning that can withstand data imputation and control signal compromising is needed. Test permanent or long-term monitoring and communications capabilities to deter physical attacks (e.g., by drones) on critical infrastructure; iii) Advancing wireless communication cybersecurity for command and control of DERs with a focus on via various network configurations – mesh networks, 5G networks, very small aperture terminal (VSAT) networks, and microwave networks.

- **Cybersecurity through advanced software solutions:** i) Develop tools and technologies that secure energy delivery or generation systems with a focus on software development in a holistic testing environment that allows for a development feedback cycle and ensures that the asset owner and operators' needs are met. For example, advanced cyber-physical power system co-simulator to identify system weak points to cyber-attack events and inform protection and hardening plans and quantify impacts on system operation; ii) Develop proof of concept algorithms that can be tested across a full range of attacks in both testbed and real environments digital twin projects to enable essential collaborator participation and their integration into the effort. Addressing the threats and vulnerabilities from the advent of edge computing, i.e., distributed computing paradigm to bring computation and data storage closer to the source of data, AI-chip deployed for anomaly detection and classification, distributed analytics.

PILLAR FIVE: Workforce training, outreach, and policy

5 UConn is committed to attracting and training the skilled and diverse workforce of the technological, policy, socio-economic and entrepreneurial ecosystem to ensure the sustainability of clean energy transition.

- **Governance and Tools integration:** The successful deployment of a low-carbon and resilient grid depends ultimately on the way grid operators will be allowed to function. There is a need to analyze and redraw governance structures for creating a cost-effective and efficient deployment of a low-carbon grid. By combining scenario analysis with policy analysis, we will identify new ways to overcome current regulatory burdens and deliver a region wide policy strategy to integrate the new structure into the current state legislations.
- **Assessing equity in resilience interventions:** With the increasing societal importance of reliable electric distribution, outage impacts are unlikely to be equal across communities, as some individuals and communities have greater political and economic resources to support resilience investments, deployment of more efficient renewables, and likely more willingness to invest in change. Currently there are no resilience metrics that can be used to identify equity in resilience and assess the outcomes of resilience interventions.

Resilience and green generation investments, such as microgrids, should be studied through a combined analysis of grid resilience under storm and climate scenarios, economic analysis of broad economic impacts, and granular analysis of consumer behavior data to understand responses and incentives.

- **Response modeling:** Identifying behavioral changes in which customers adapt to lack of reliability and the effects of increased behind-the-meter adoptions of low-carbon technologies. Examining how customer behavior, e.g. total electricity usage or timing of us, changes upon various technological adoptions. Conduct experiments and surveys for customer infrastructure subsidies to determine optimal subsidies stratified across demographics and locations.
- **Training:** Engage in research undergraduate students from underrepresented minority and tribal communities.

  Continue training the engineering workforce on state-of-the-art tools for the power grid through the Eversource Energy Center's Grid Modernization Certificate program.

  Continue educating graduate students through Ph.D. and Master degree programs in Engineering, Natural Resources, Social Sciences, Economics, Political Science and Business.