# Research Co-design Activity

## A. Purpose of Co-design:

The ultimate goals of this co-design activity are to:

- Directly involve all members of a group to make decisions together that would affect their daily life
- Ensure group members have a sense of belonging through working a project together
- Challenge the critical thinking skills and awareness of those involved
- Incorporate multiple disciplines to address a complex issue
- Foster relationships between those implementing the decisions and those living with the decisions to build trust and inspire future collaborations

## B. CURENT Student Co-design Activity

**In this co-design activity, we are asking that you help us plan the future research direction(s) of the center.**

**This co-design activity is loosely-structured based on students' research interests so that students can ask questions and receive answers that will allow them to help brainstorm potential ideas for research topics.**

### Co-design Agenda:

1. Prior to the activity, faculty will present an overview of CURENT's roadmap and answer questions related to the road map; this is the chance for all students to ask specific questions.
    a. A copy of the road map is found on the next page
2. Students will select 1-2 areas they are interested based on the research thrusts and will submit choice by 5/14 via Google Form (https://goo.gl/forms/vxi6gzQhXRhXgV463 )
3. During the co-design activity, students will work in their small group (about 10 members) to create new and innovative ways **based on their knowledge and future research interests** to fulfill CURENT's mission through their research.
    a. The final deliverable will be 1) a written summary emailed to education@curent.utk.edu and 2) a flowchart or mind map that explains their idea CURENT faculty and students (only 1-2 member from each group should present).
    b. Faculty will be on hand to serve as subject matter experts throughout the activity
    c. As a guideline, students should have the following roles:
        i. **Facilitator (1 student):** Responsible for starting the conversation and making sure that everyone is on task and stays on task
        ii. **Recorder (1 student):** Responsible for taking notes and recording critical points from discussion
        iii. **Spokesperson/presenter (1-2 students):** Responsible for reporting-out discussion ideas and deliverable
        iv. **Questioner (1 student):** Pushes back when consensus is reached to quickly, focuses on what-ifs and varied points of view
        v. **Designers (1-2 students):** Designs the final deliverable
        vi. **Encourager (1 student):** Asks probing questions and encourages deeper thinking

vii. **Time-Keeper (1 student):** Responsible for watching the time and working with facilitator to keep group on track

➢ **What You Know (focusing on Generation III for this activity)**

## CURENT System Definition and Specifications

| **Generation I (Y1-Y3)** | **Generation II (Y4-Y6)** | **Generation III (Y7-Y10) – We are here** |
|---|---|---|
| • Regional grids (based on 48 machine Northeast system and 190 bus WECC system), with >20% renewable (wind, solar)<br>• Grid architecture to include HVDC trunk lines, at least one multi-terminal DC grid for off-shore wind farm<br>• System scenarios demonstrating a variety of seasonal and daily operating conditions<br>• Sufficient monitoring to provide measurements for full network and parameter observability as well as robustness against contingencies, bad topology or measurement data<br>• Closed-loop non-local frequency and voltage control using PMU measurements<br>• Renewable energy sources and responsive loads to participate in frequency and voltage control | • Reduced interconnected EI, WECC and ERCOT system, with >50% renewable (wind, solar) and balance of other clean energy sources (hydro, gas, nuclear)<br>• Grid architecture to include UHV DC trunk lines connecting with regional multi-terminal DC grids, and increased use of power flow controllers,<br>• System scenarios demonstrating complete seasonal and daily operating conditions and associated contingencies, including weather related events impacting wind and solar<br>• Full PMU monitoring at transmission level with some monitoring of loads<br>• Fully integrated PMU based closed-loop frequency, voltage and oscillation damping control systems, and adaptive RAS schemes, including renewables, energy storage, and load as resources, demonstrating improved transfer limits and reduced required reserves | • Fully integrated North American system, with >50% renewable (wind, solar) and balance of other clean energy sources (hydro, gas, nuclear)<br>• Grid architecture to include UHV DC super-grid and interconnecting overlay AC grid<br>• Future load composition (converter loads, EV loads, responsive loads), selective energy storage (including concentrated solar with thermal energy storage)<br>• Fully monitored at transmission level (PMUs, temperature and so on). Extensive monitoring of loads in distribution system<br>• Closed loop control using wide area monitoring across all time scales and demonstrating full use of transmission capacity<br>• Coordinated renewable energy source control over wide area for minimum reserves |

## Reseach Roadmap and Key Milestones by Thrust

| Thrust | | Generation I (Y1-Y3) | Generation II (Y4-Y6) | Generation III (Y7-Y10) |
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| **System Testbeds** | **Large Scale System Testbed** | • Regional grid models with > 20% penetration of renewables and HVDC connections<br>• Model development for primary and secondary frequency and voltage controls in regional grids<br>• Scaled down system models suitable for testing in RTDS and HTB<br>• Scenario development to include diverse system operating conditions | • Reduced North American system model with > 50% penetration of renewables and HVDC connections<br>• Extension of frequency and voltage control models to North American grid and for damping control and transient stability control<br>• Communication system modeling including cyber attacks<br>• Scenario development for North American grid | • Large model of North American system with >50% renewables and HVDC connections<br>• Fully integrated system model of real time communication, coordinated control, actuators, monitoring and load response<br>• Detailed scenarios for contingencies and cyberattacks sufficient to demonstrate resilience |
| | **Hardware Testbed** | • Hardware implementation of the power electronics based emulators, including large wind / solar / storage farm emulation<br>• Integrate PMU/FNET data into HTB<br>• Multiple load and scenario demonstrations (multi-terminal HVDC, hybrid AC/DC, multi-area oscillation and control, high renewable energy penetration) | • Implementation of sensing, monitoring, actuation, and protection in real-time<br>• Integrate with real-time simulation<br>• Scenario demonstrations (multiple HVDC links between wide areas, major tie line and wind farm outage dynamic effects, coordinated power flow control over large distances, demonstrate system resilience to attacks, energy storage impact) | • Coordinated high penetration renewable control demonstration<br>• Automatic real time reconfiguration for selected outage scenarios<br>• Ultra-wide-area coordinated real-time communication and control on a system hardened against coordinated cyber attack |

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| Monitoring | Situational Awareness & Visualization | • Online analysis tools<br>• Event propagation<br>• Dynamic clustering<br>• Interactive visuals<br>• Visualization | • Stability margin, reactive power display<br>• Fast rendering for real time visualization to aid system operators | • Dynamic sharing of large-scale visualization<br>• Concurrent view of multiple attributes<br>• Multi-event detection |
| | Wide Area Measurement | • Improve frequency and angle dynamic precision<br>• Develop prototypes<br>• Investigate alternate high precision timing<br>• Non-contact fields based measurement | • Improve algorithm speed and accuracy<br>• Consider high power electronics conditions<br>• Advanced data analytics<br>• Cyber robustness | • Expand dynamic range<br>• EMI hardening<br>• Advanced data analytics<br>• Secure timing source<br>• Improve cyber robustness |
| Modeling and Estimation | Estimation | • Phasor only state estimator (NPCC system as test-bed)<br>• Phasor data error and contingency management<br>• Resiliency against bad data, sensor failures and data latency<br>• Impact of communication delays | • Multi-Area phasor only estimator<br>• Network model error detection and identification method<br>• development, testing and evaluation<br>• Robust and computationally efficient dynamic state estimator: Method development, testing and evaluation | • Testing of phasor state estimator using recorded wide-area measurements<br>• Develop a three-phase linear estimator<br>• Combining robust estimation and voltage stability modules using LTB |
| | Communication & Cyber Security | • Impact of communication delays in estimation<br>• Detection and identification of network disturbances<br>• Defense strategies against cyber-attacks on networks carrying PMU data<br>• Secure outsourcing of intensive computations method | • Develop architectures for secure communications for wide-area SCADA systems including support for encryption, authentication, key management, intrusion detection, and network security<br>• Determine effective security countermeasures for SCADA systems<br>• Secure outsourcing of intensive computations testing | • Develop ways to ensure continuous upgrade of security measures<br>• Predictive delay estimation<br>• Self-healing<br>• Online monitoring and automated alarm |

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| | **Modeling Methodology** | - Modeling spatial and temporal uncertainties in power and communication networks | - Quantifying vulnerability against uncertainties in network models<br>- Develop a tracking estimator for dynamic load models based on synchronized measurements<br>- Fast Time-Domain Simulations | - Application of developed models for large-scale transmission grids and for LTB. |
| **Control** | **Control Design and Implementation** | - Frequency and voltage control design and implementation for CURENT systems with 20% renewable penetration | - Fully integrated PMU-based closed-loop frequency and voltage control systems for 50% renewable penetration, including loads and storage systems as resources<br>- PMU-based system specific RAS schemes | - Closed-loop control using wide area monitoring across all time scales with full use of transmission capacity, for >50% renewable penetration<br>- Coordinated renewable energy source control over wide areas for minimum reserves |
| | **Control Architecture** | - Multi-scale wide-area energy systems control (Modeling and control of renewables, wide-area control methodologies: frequency control, voltage control, phasor measurements, flat control) | - Control of ultra-wide interconnected systems (HVDC and FACTS controllers, dynamic demand response control, storage systems, resilient control design) | - Multi-level distributed wide-area control, with ubiquitous control and measurement points available from renewable interfaces and energy storage systems |
| | **Economics & Social Impact** | - Next generation of operation cooperation<br>- Generation planning issues<br>- Basic individual and community models | - Incentive structures for inducing socially optimal private generation investment and demand response<br>- Strategies for bidding renewable energy into the electricity market | - Transmission planning, stochastic optimization<br>- Develop methods for socially optimal transmission investment planning<br>- Field testing of models |

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| **Actuation** | **Actuation Functions** | • Renewable energy sources, HVDC & FACTS for frequency and voltage control (characterized the true capabilities of wind and PV converters, multi-units vs. aggregated units)<br>• Renewable converters as compensators (virtual impedance for series compensation) | • Renewable energy sources, HVDC, FACTS for grid dynamics support (e.g., oscillation damping) (RES dynamic capability characterization and design)<br>• Multifunctional power flow controller (coordinated, multi-mode control of renewable and storage, and load; converters and system stability) | • Coordinated renewable energy source control over wide area<br>• Future loads and energy storage<br>• Actuation functions for dynamics across all time scales |
| | **Actuator & Transmission Architecture** | • Regional multi-terminal HVDC grid for off-shore wind (design of 4-terminal HVDC grid for NPCC, series/parallel grid topology & control)<br>• Alternative transmission scheme (hybrid HVAC/HVDC transmission for long line)<br>• DC grid component technology (MMC design, control under ac fault conditions, HV DC/DC converter design) | • UHV DC trunk lines and regional multi-terminal DC grids (architecture evaluation and design)<br>• DC grid component and system technology (fault tolerant converters, WGB based converters, protection, fault location and isolation, ac grid and renewable source integration) | • AC and DC super-grid design and wide-area control<br>• WBG based converter applications |