SCC: Empowering Smart and Connected Communities through Programmable Community Microgrids

Award No# 2018492

Peng Zhang, Stony Brook University

IRG, FY2018

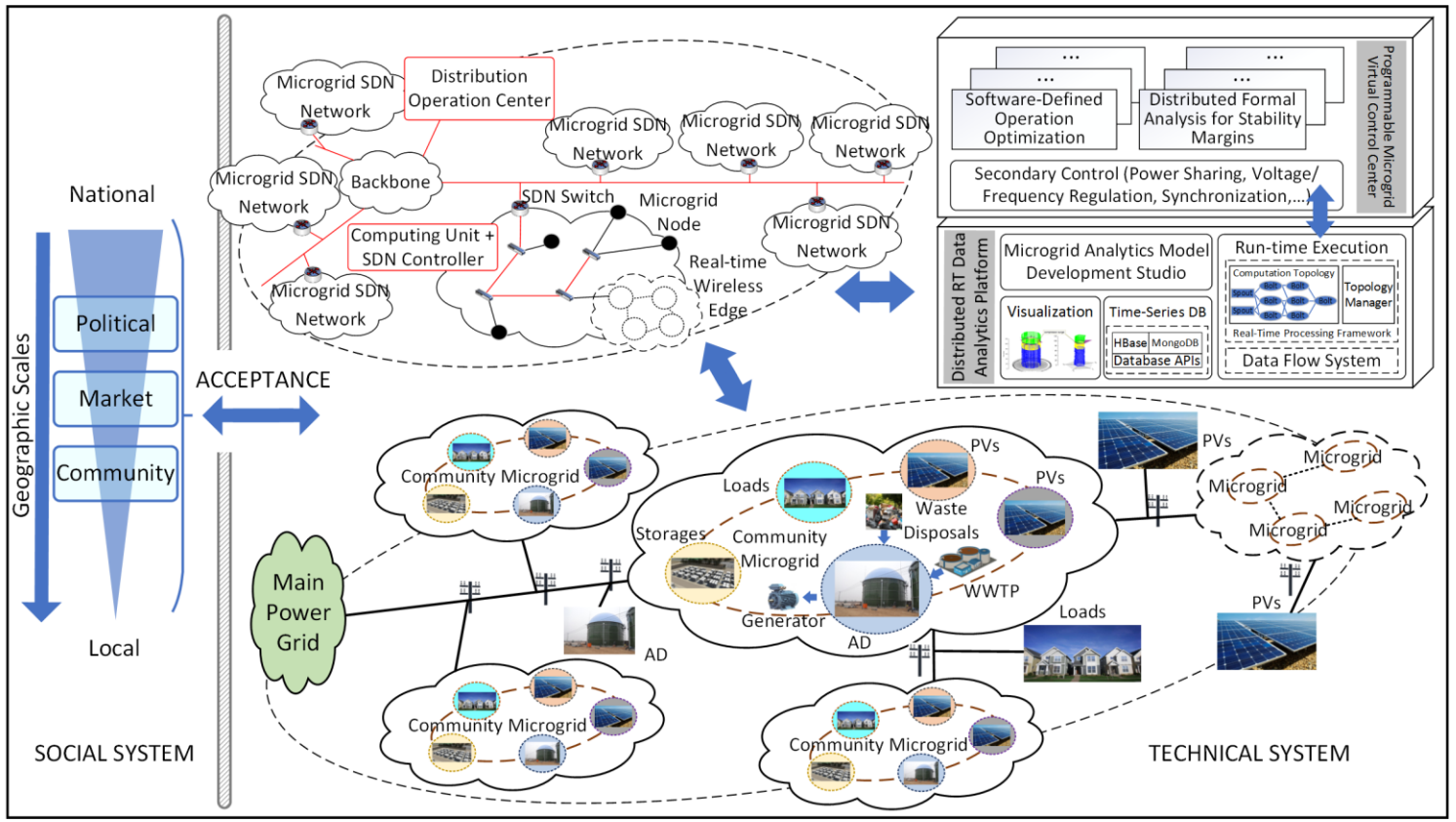
Principal Research Investigators

- Peng Zhang, Stony Brook University
- Peter Luh, University of Connecticut
- Baikun Li, University of Connecticut
- Fei Miao, University of Connecticut
- Carol Atkinson-Palombo, Univ. of Connecticut
- Amir Herzberg, University of Connecticut

Community Partners

- Joel Rinebold, Connecticut Center for Advanced Technology
- Mark Wick, Energy and Innovation Park, New Britain
- Erin Steward, Mayor of New Britain
- Michael Ahern, Worcester Polytechnic Institute
- Roderick Kalbfleisch, Eversource Energy
- Rick Conant, RLC Engineering
- Annie Philip, PSEG Long Island

Project Overview



- The main objective of this project is to create smart programmable microgrids (SPMs).
- Our key innovation is to virtualize microgrid functions, making them software-defined and hardware-independent, so that converting DERs to community microgrids becomes affordable, autonomic, and secure.
- This project will provide groundbreaking, replicable technologies to modernize cost-effectively America's energy infrastructures in the S&CC and could transform today's community power infrastructures into tomorrow's flexible services towards self-configuration, self-healing, self-optimizing, and self-protection.

Project Overview

Use-Inspired Research

Although microgrids are effective and promising, transforming community power infrastructures into microgrids remains prohibitively difficult.

Working with community microgrid partners EIP, CCAT, The Plant, etc., several critical issues were identified

- Hardware dependence
- Lack of scalable, high-speed communication and computing infrastructure
- Limited and unscalable analytics
- Lack of dispatchable generation to enable seamless islanding
- Cyber-security and privacy concerns

Fundamental Research Contributions

- Architect a smart programmable microgrid platform
- Pioneer a concept of software-defined operation optimization for microgrids
- Devise formal analysis methods to ensure microgrids stability
- Establish software-defined security and privacy solutions
- Unlock the potential of community facilities, e.g., converting anaerobic biomass digesters (AD) into environmentally friendly and dispatchable DERs

Project Update (2020 - Present)

Programmable Microgrids

Architect programmable microgrid platform

- Implicit Zbus Gauss power flow
- Quantum electromagnetic transients program
- Networked microgrids power flow (APF + CPF+)

Pioneer software-defined operation optimization

- Distributed and asynchronous active fault management
- Distributed and asynchronous operational optimization

Devise formal methods to ensure microgrids stability

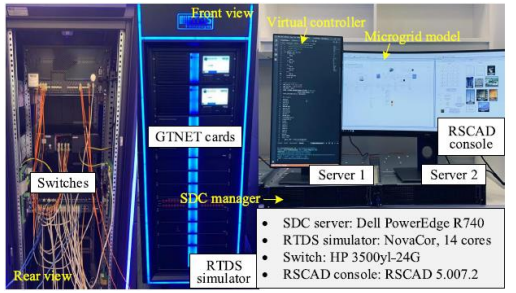
- Reachable power flow
- Reachable eigenanalysis
- Reachable dynamics of networked microgrids

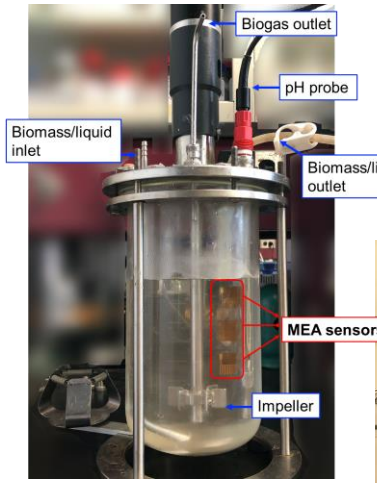
Establish software-defined security and privacy solutions

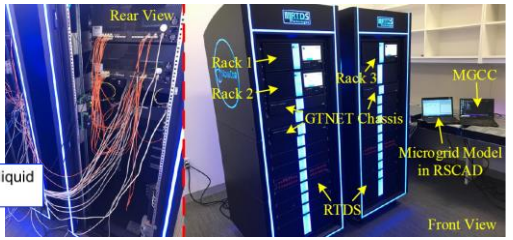
- Programmable adaptive security scanning
- Programmable quantum networked microgrids
- Software-defined cyber-energy secure
- Quantum-secure microgrid

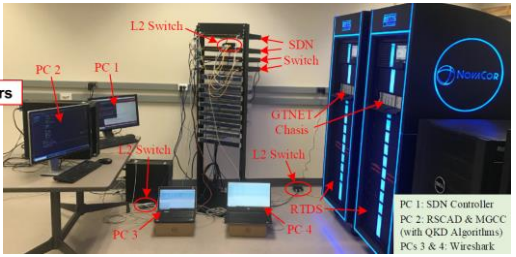
Biogas Prediction Optimization

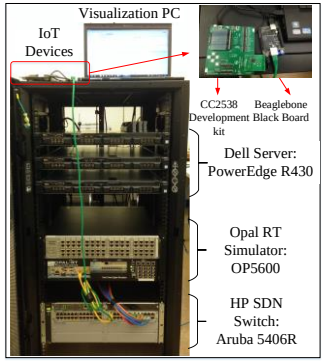
- MEA sensors profiling
- Feedback control from massive data
- Better biogas production prediction
- New data-driven models

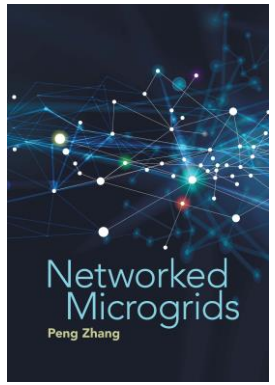












Project Evolution

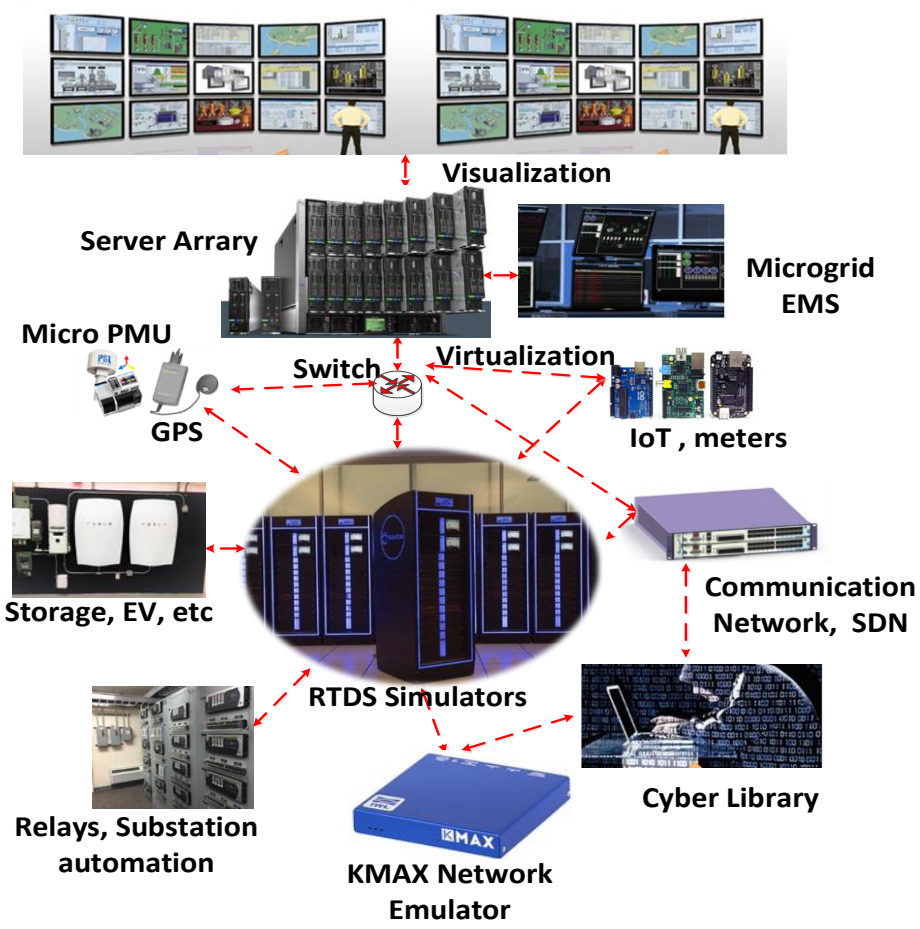
- Interactions with Community Partners
  - Demands from Community Microgrid Owners
    - Technologies offering high resilience (e.g., six nines availability, quick bounce back from outage)
    - Technologies for extreme renewable integration
  - Practical Issues in Microgrid Operation
    - Ubiquitous measurement & communication delays and cyber issues
    - Reliance on fidelity & reliable data vs data deficiencies in real microgrids
  - New Techniques
    - Online distributed control to tackle uncertainties
    - Distributed and asynchronous active fault management
    - Provable resilient microgrid control
    - Encrypted control, with stability guarantee
- Establishing Smart Programmable Microgrids Ecosystem
  - So far, our team has been working with 20 community and industry partners
  - Strong collaboration with Brookhaven National Lab as affiliated scientists

Evaluating Project Impact on Communities

- Our learning based security tool can effectively eliminate the botnets attacks that break electric transformers in communities.
- Programmable adaptive security scanning for networked microgrids can accurately localize and mitigate various cyberattacks on microgrid controllers and communication networks.
- Augmented continuation power flow (CPF+) can mitigate voltage collapses in networked community microgrids and provide online power flow analytics for planning, operation and remedial control of community microgrids.
- Distributed and asynchronous operational optimization reduces the operation cost of networked microgrids by 20%.
- ODE-based reachable dynamics analytics can provide online stability guarantee for networked microgrids under disturbances.
- Reachable power flow (ReachFlow) and its variants can efficiently provide fast state monitoring for networked microgrids even when the operating points have ‘random walks’ driven by renewables and disturbances.
- Reachable eigenanalysis can provide small-signal stability for networked microgrids under ‘random walks’ of equilibriums.
- A revisited, implicit Zbus Gauss (Grev) can accurately perform power flow analysis for highly meshed community microgrids.
- A distributed and asynchronous active fault management (DA-AFM) is a powerful tool to ensure networked microgrids ride through various grid faults and short circuits, making networked microgrids reliable resilience resources.
- Our software-defined microgrid control, which leads to the genesis of decoupled cyber-physical microgrids, allowing for a purely hardware-independent microgrid controller, which can reduce the cost of building a community microgrids by 30% or more.
- The difference of the temperature increasing rate with a heating pad, different steady-state temperature and different heat transfer under the shocks between three locations (deep, middle, top) demonstrate that mixing indeed affected heat transfer in the AD system. The irregular pH variation tendency also showed the heterogeneity of the AD reactor.

Anticipated outcomes & success measures for next year

- Build Programmable Microgrid prototype on large real-time testbed.
- Incorporate our new networked grids power flow, DA-AFM, resilient distributed control, DA-SLR, software-defined control technologies in the cyber-layer of our resilient programmable networked microgrids.
- Integrate AD MEA sensor profiling with machine learning and time series analysis models to predict biogas production with only several key parameters (pH, conductivity, ORP, temperature) under different conditions, establish better biogas production prediction than traditional ADM1 with thousands of immeasurable parameters, to enhance the entire system model design and analysis.
- Establish a feedback control mechanism between microgrid demand and AD system supply. Quantum-level simulation of the biogas production through a quantum computer can facilitate precise control of supply rate, methane ratio, and intermediate products, which maximizes the stablility and controllability of the clean energy production.
- Work with community partner to discuss technology transfer between our team and the city.



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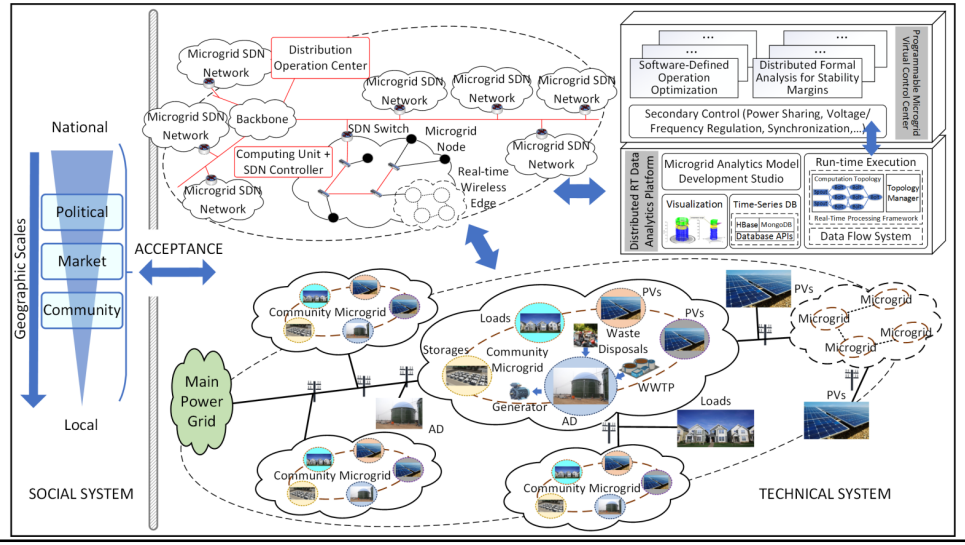
Visual Schematic



Project Vision

- Enable software-defined, hardware-independent community microgrid functions
- Establish a programmable platform that integrates SDN, real-time computing, and IoT to enable:
  a) software-defined operation optimization, b) conversion of community facilities such as waste management facilities into dispatchable resources, and c) networking of community microgrids, without requiring expensive grid/communication infrastructure modifications

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