Introduction to Smart Grid and Microgrids

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Smart Grid and Microgrid Technologies with DER-CAM Training
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About the speaker

- Ph.D. Illinois Institute of Technology, 2007

- Affiliate Professor, Auburn University (2011-)

- Adjunct Professor, University of Notre Dame (2014-)

- Editor, *Applied Energy, Journal of Energy Engineering*

- Editor-in-Chief, *IEEE Transactions on Smart Grid*

- Authored/co-authored over 200 journal articles and 50 conference publications and 5300+ citations. Recipient of the IEEE PES Power System Operation Committee Prize Paper Award in 2015.

- Secretary of the IEEE Power & Energy Society (PES) Power System Operations committee and past chair of the IEEE PES Power System Operation Methods subcommittee

- Held visiting positions in Europe, Australia and Hong Kong including a VELUX Visiting Professorship at the Technical University of Denmark (DTU)

- Technical program chair of the IEEE Innovative Smart Grid Technologies (ISGT) conference 2012

Argonne is America's First National Laboratory and one of the World's Premier Research Centers
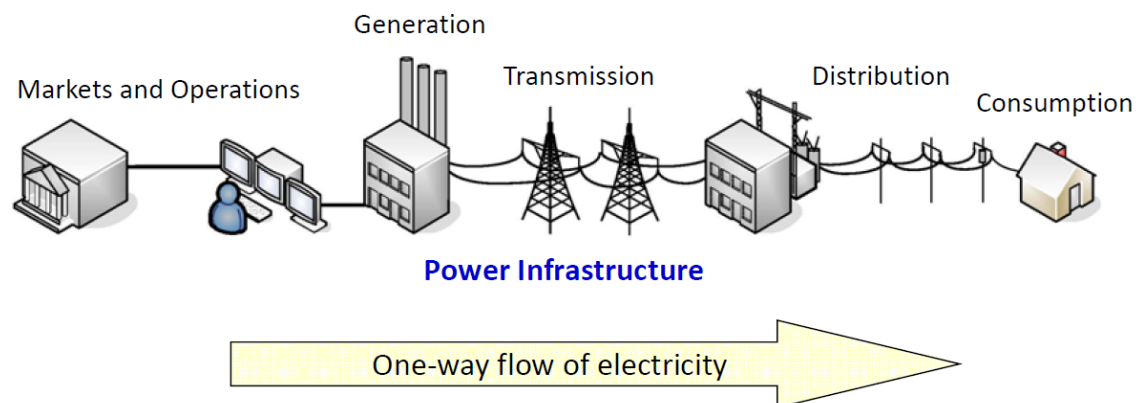
- Founded in 1943, designated a national laboratory in 1946

- Part of the U.S. Department of Energy (DOE) laboratory complex
  - 17 DOE National Laboratories

- Managed by UChicago Argonne, LLC
  - About 3,398 full-time employees
  - 4,000 facility users
  - About $760M budget
  - Main site: 1500-acre site in Illinois, southwest of Chicago

- Broad R&D portfolio and numerous sponsors in government and private sector
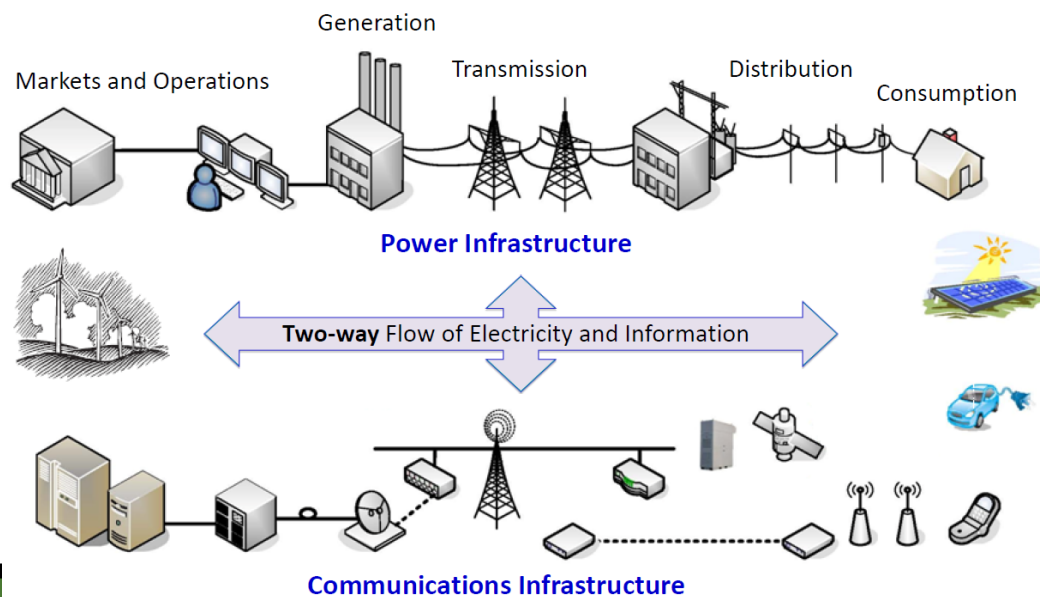
- Three Nobel Prize Laureates
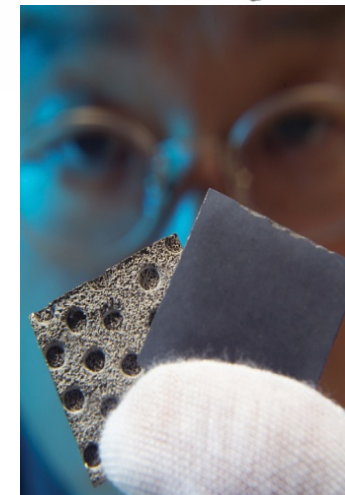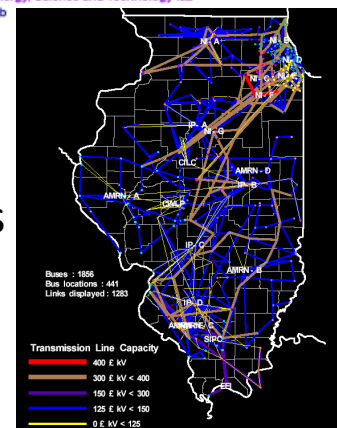
Grid Modernization and a Vision for the Future

- Centralized generation
- Generation follows load
- One-directional power flow
- Limited automation
- Limited situational awareness
- Consumers lack data to manage use
- Limited accessibility for new producers

- Centralized + distributed generation
- Variable resources
- Consumers become producers
- Multi-directional power flow
- Flexible load

Source: ABB 2009; Texas Tech 2012
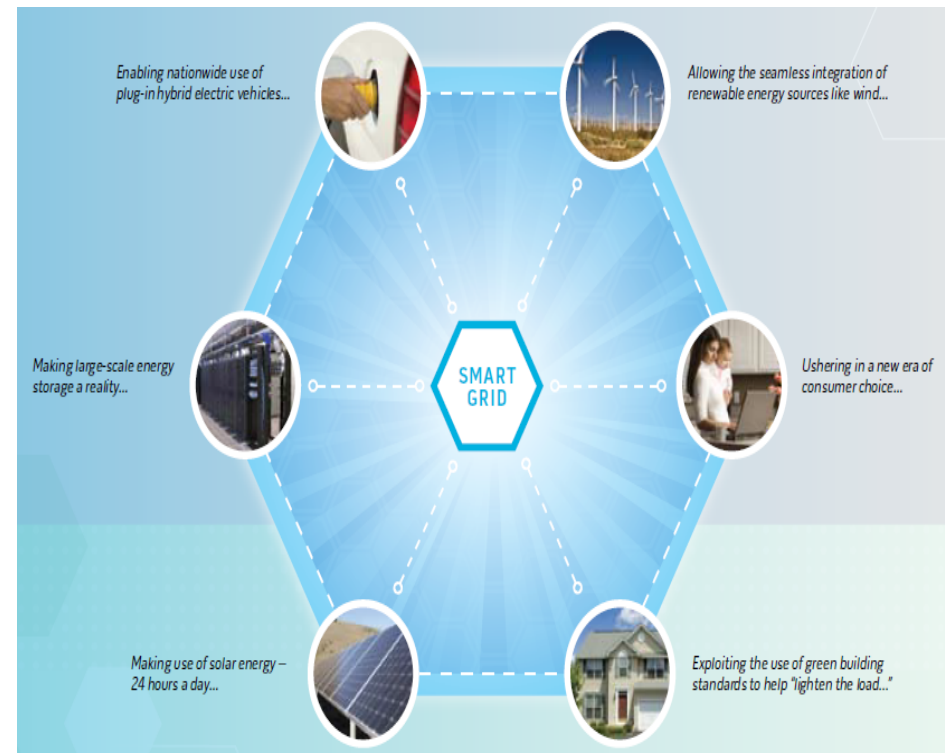

Traditional Power Grid:

Power Infrastructure

One-way flow of electricity

Future Smart Grid:

Power Infrastructure

Two-way Flow of Electricity and Information

Communications Infrastructure

My Version of the Future Power Grid

❑ **Integrative** Planning and operation (temporal), information technology and power engineering (cyber), integrated T&D (spatial), supply and demand (system-wide)

❑ **Interdependent** coupling of critical infrastructures (e.g., gas, water, power, communications.)

❑ **Robust, Flexible and Resilient** (e.g., uncertainty and variability of clean renewable energy, extreme weather events)

❑ **Hybrid Dynamic Control Architecture** centralized (e.g., HPC for faster-than-real-time interconnection-level simulation AND decentralized (e.g., microgrids, electric vehicles, power electronics-interfaced generation)

❑ **Cyber and Physical Secure**

Enabling nationwide use of plug-in hybrid electric vehicles...

Allowing the seamless integration of renewable energy sources like wind...

Making large-scale energy storage a reality...

SMART GRID

Ushering in a new era of consumer choice...

Making use of solar energy – 24 hours a day...

Exploiting the use of green building standards to help "lighten the load..."

Source: DOE, 2011

New York State Reforming Energy Vision (REV) Initiative

- Increasing requirements for grid resilience after Hurricane Sandy

- Distribution – level electricity market

- Diverse participants/resources (DR, DG, microgrids, storage, etc.)

- Distribution System Platform (DSP)

- Market platform and market rules

- Challenges exist – distribution OPF, market clearing, etc.

(Source: The Clean Coalition)
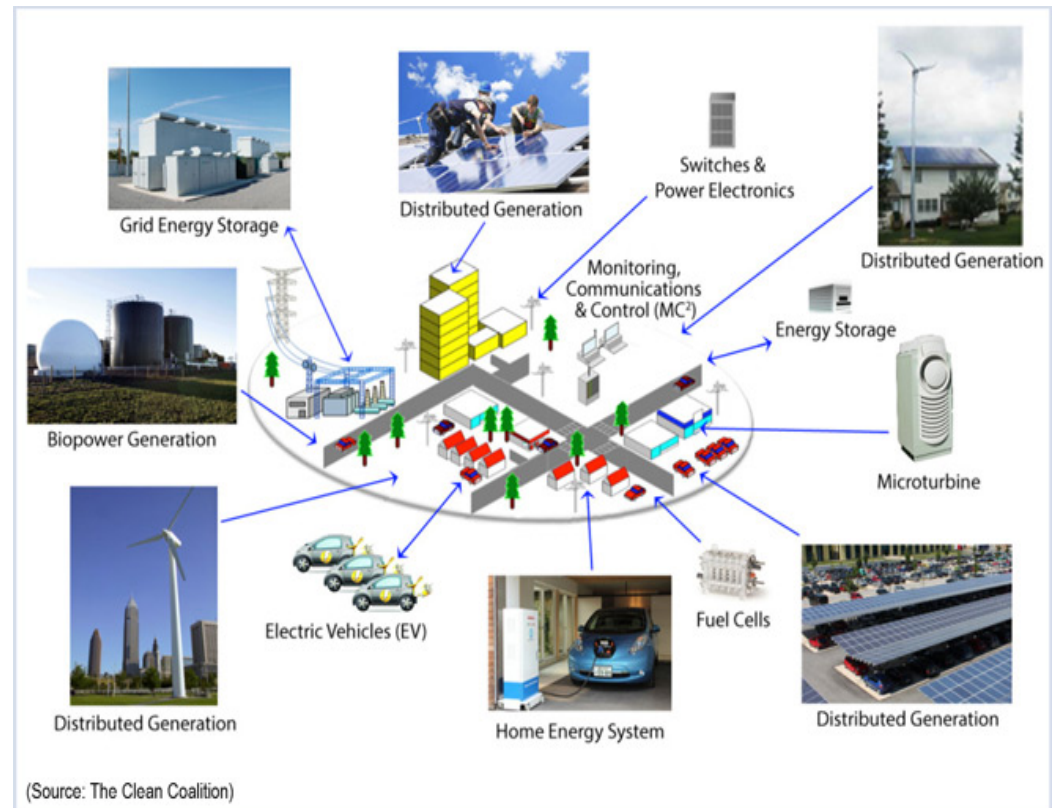
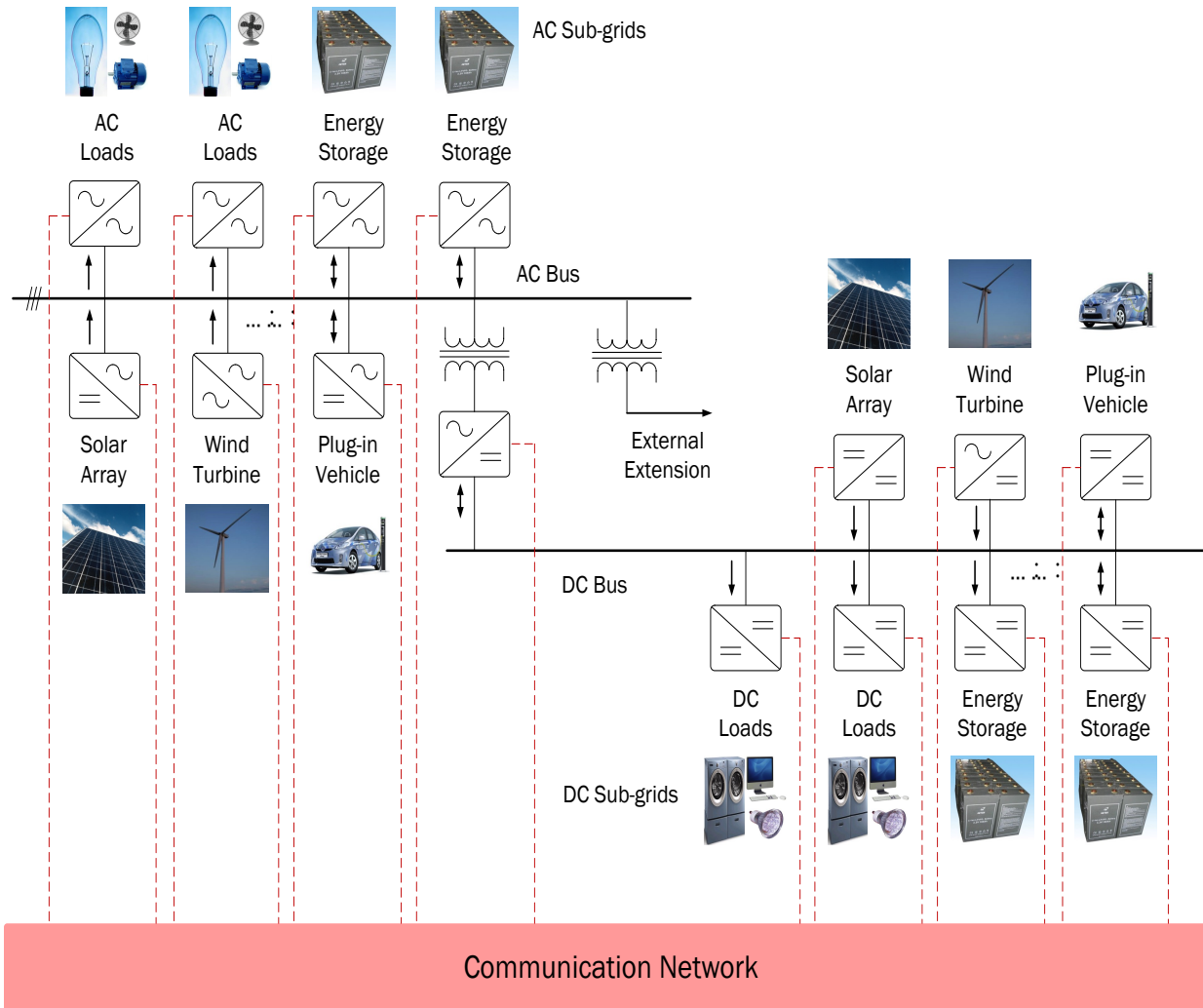Argonne is supporting NY REV initiative

Introduction to Microgrid

- The concept of microgrid was first introduced as a solution for the reliable integration of DERs, including Energy Storage Systems (ESSs) and controllable loads.

- Grid-connected and island modes and transition between the two modes

- Reliability, Efficiency, Security, Quality, Sustainability

Microgrid Definition

U.S. Department of Energy Microgrid Exchange Group: A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode.

Introduction to Microgrid

AC Sub-grids

AC Loads

AC Loads

Energy Storage

Energy Storage

AC Bus

Solar Array

Wind Turbine

Plug-in Vehicle

External Extension

Solar Array

Wind Turbine

Plug-in Vehicle

DC Bus

DC Loads

DC Loads

Energy Storage

Energy Storage

DC Sub-grids

Communication Network

**Coordinated control and operation of:**

- **Distributed sources, loads and energy storage**
- **Power electronics and power system**
- **AC sub-grid and DC sub-grid**

DOE FOA 997 - Research, Development, and Testing of a Master Controller with Applications to the Bronzeville Community Microgrid System
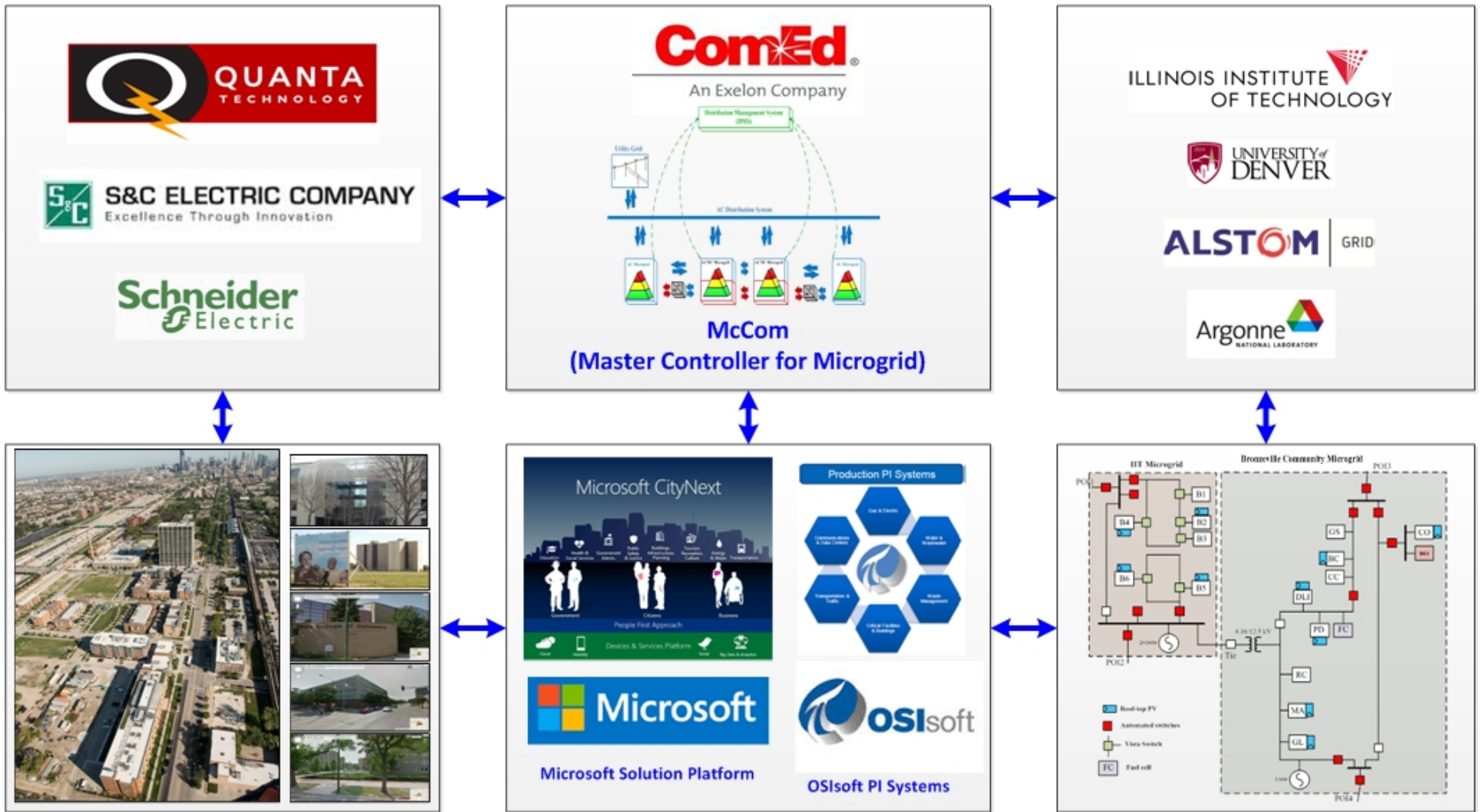
DOE FOA 997 - Research, Development, and Testing of a Master Controller with Applications to the Bronzeville Community Microgrid System

- **Goal**: Develop a Master Controller for a Community (McCom) with applications to the Bronzeville Community Microgrid (BCM), and develop an interconnected microgrid system design and test plan in the Chicago's Bronzeville community.

- **Tasks**: (1) a microgrid testbed; (2) autonomous microgrid clusters; (3) cost/benefit analysis of alternatives for microgrids; (4) new reliability and power quality standards based on customer needs; (5) new rates and tariffs to correlate microgrids costs/benefits and customer payments; (6) terms and conditions of service for microgrid customers; (7) market mechanism; (8) service differentiation and rates

- **Impact**: McCom will help meet the DOE targets: (1) 98% reduction in outage time of critical loads, (2) 20% reduction in emissions, and (3) 20% improvement in system energy efficiencies.
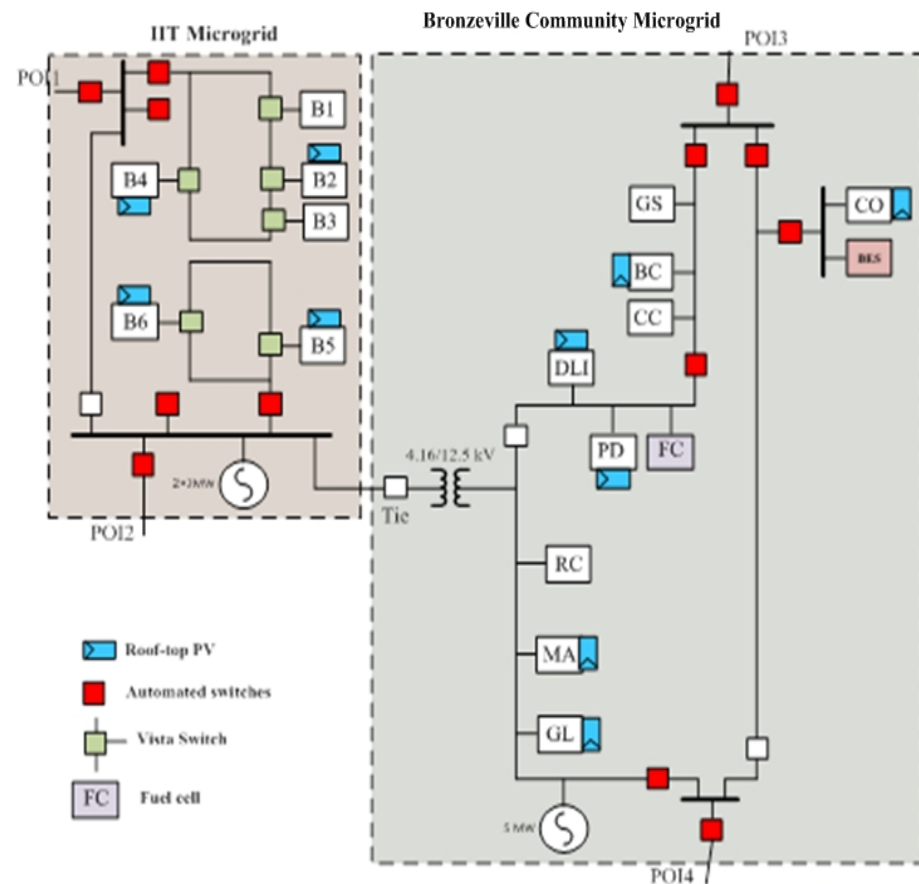
Design, Implementation, and Testing Advanced Microgrids

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News Release

Media Contact:
312-394-3500

FOR IMMEDIATE RELEASE

U.S Department of Energy Awards ComEd $4 Million for Renewable Technology
Second DOE award to help bring solar energy and batteries to Chicago's Bronzeville neighborhood

CHICAGO (January 20, 2016) — ComEd received a $4 million award from the U.S. Department of Energy SunShot Initiative to design and deploy solar and battery storage technology within its planned microgrid demonstration project in Chicago's Bronzeville neighborhood. This award will enable the most sophisticated solar project in the Midwest, while also helping ComEd and the communities we serve learn more about important te... future.

Argonne NATIONAL LABORATORY

NREL NATIONAL RENEWABLE ENERGY LABORATORY

PES Power & Energy Society®

ComEd Community Microgrid in Bronzeville Chicago
Partnered with ComEd Co. to design and test the community microgrid in Bronzeville Chicago
Interactions between Multiple Microgrids and Distribution System
Impact analysis between multiple microgrid controllers and ADMS
Reconfigurable Microgrids to Mitigate the Influence of Natural Disasters
Implement dynamically reconfigurable microgrids to facilitate service restoration after disasters
Real-time Testbed for Testing Microgrid Controllers and Advanced Applications in DMS
Partnered with Eaton Co. to implement the real-time testbed based on OPAL-RT platform
Optimal Design Tool for Remote, Resilient and Reliable Microgrids
Partnered with LBNL and other national labs to develop optimal design tool for remote microgrids

Power Grid Resilience

- PRESIDENTIAL POLICY DIRECTIVE/PPD-21

  The Presidential Policy Directive (PPD) on Critical Infrastructure Security and Resilience advances a national unity of effort to strengthen and maintain secure, functioning, and resilient critical infrastructure.

- Bulk Power System Restoration
  - Integrated Restoration Model
  - Restoration Solution Refinement
  - Solution Algorithms
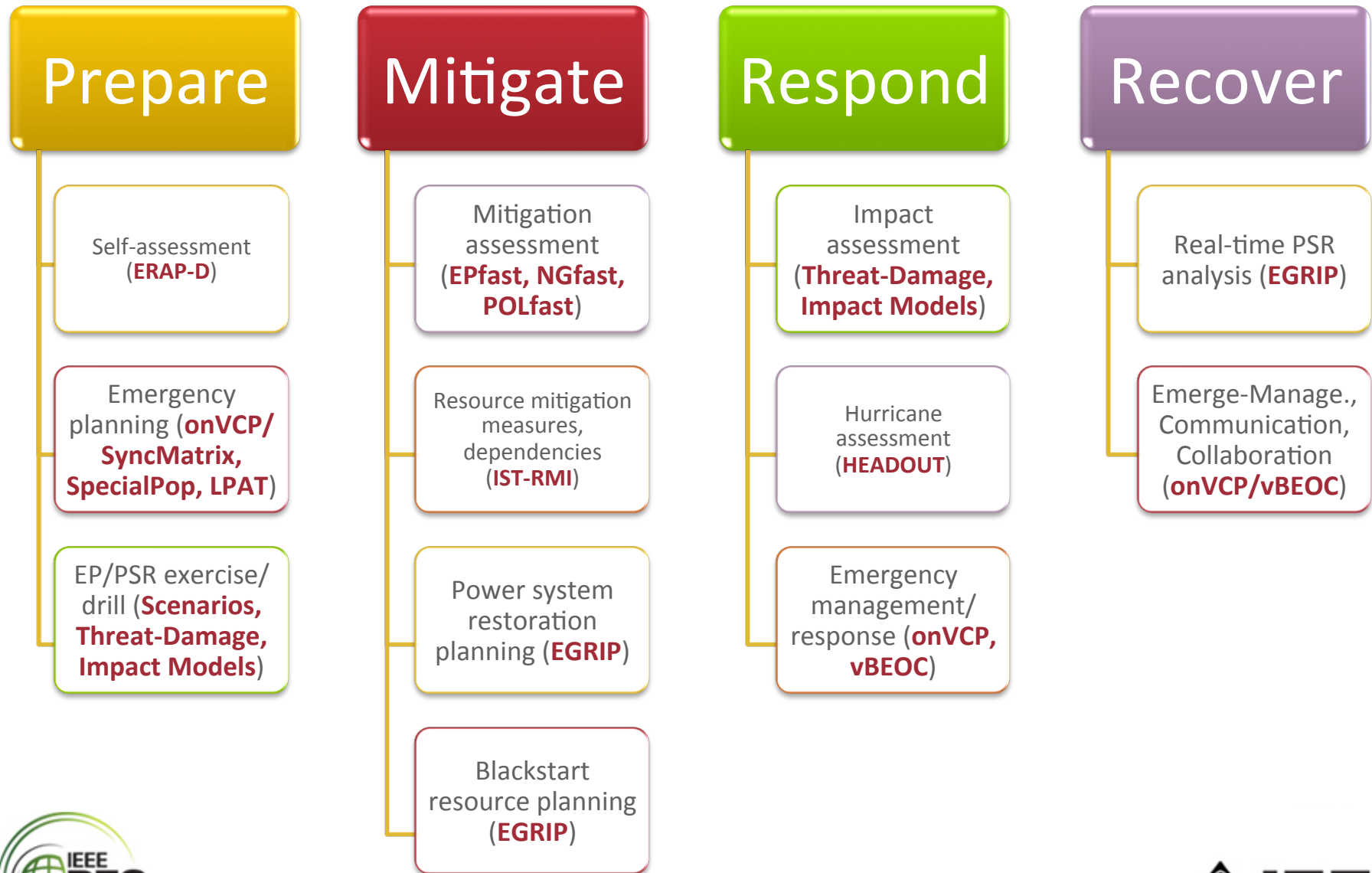 - Optimal Black-Start Resource Procurement

- Distribution System Restoration
  - Microgrid formation
  - Network reconfiguration
  - Crew scheduling

- Working closely with FEMA, MISO and PJM

- Tied to Smart Cities

Argonne's Comprehensive Set of resilience tools

Prepare

Self-assessment (**ERAP-D**)

Emergency planning (**onVCP/ SyncMatrix, SpecialPop, LPAT**)

EP/PSR exercise/ drill (**Scenarios, Threat-Damage, Impact Models**)

Mitigate

Mitigation assessment (**EPfast, NGfast, POLfast**)

Resource mitigation measures, dependencies (**IST-RMI**)

Power system restoration planning (**EGRIP**)

Blackstart resource planning (**EGRIP**)

Respond

Impact assessment (**Threat-Damage, Impact Models**)

Hurricane assessment (**HEADOUT**)

Emergency management/ response (**onVCP, vBEOC**)

Recover

Real-time PSR analysis (**EGRIP**)

Emerge-Manage., Communication, Collaboration (**onVCP/vBEOC**)

Bulk Power System Restoration - Highlights of Our Modeling and Analysis Approach

- Integrated model that simultaneously optimizes system sectionalization and generator startup leading to a global optimal solution
    - Maintain load-generation balance
    - Minimize overall restoration time

- Advanced simulator that validates restoration plans (e.g., line overloading, frequency excursion, voltage limits, etc.)

- Integrated restoration of both bulk power and distribution systems
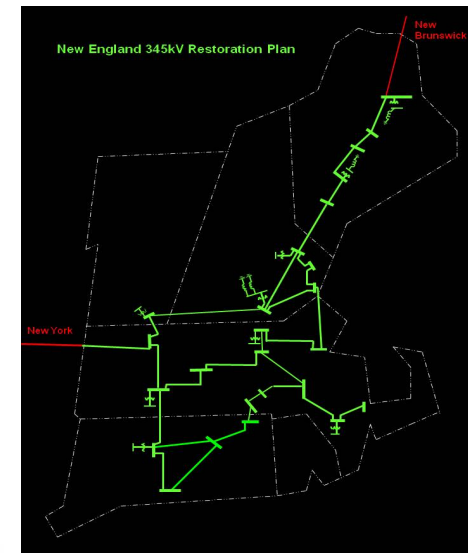
Bulk Power System   **Distribution System**
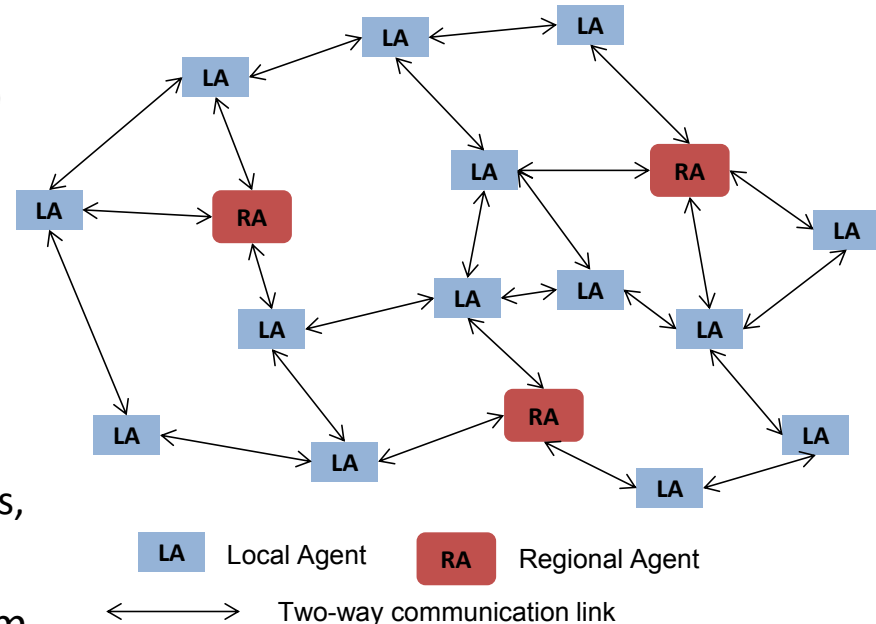
Bulk power system restoration
- Integrated optimization model (produces an initial restoration plan)
- Power system simulator (checks restoration plan feasibility)

Distribution system restoration
- Distributed multi-agent coordination scheme for global information discovery
- Dynamic microgrid formation using distributed generation

Distribution System Restoration - Our Approach

- Utilize distributed generators (DGs) and automatic switches to form several microgrids after a large natural disaster

- Continue supplying critical loads, after major grid faults

- Use distributed multi-agent coordination scheme for global information discovery: increased resilience over centralized communication schemes (single point of failure)

- Objective: maximize the total weighted load picked up by forming microgrids energized by DGs

- Mixed integer linear programming (MILP) formulation considering both topology and operational constraints

  - Decision variables: ON/OFF status of remotely controlled automatic switches (binary); output of DG (continuous)

  - Constraints: Topology constraints, power flow constraints, voltage range constraints, distribution condition constraints

- Leads to more resilient distribution system

LA Local Agent   RA Regional Agent

⟷   Two-way communication link

Reference: C. Chen, J. Wang, F. Qiu, D. Zhao, Resilient Distribution System by Microgrids Formation After Natural Disasters, IEEE Transactions on Smart Grid, in press.

Conclusions

- Our electric power industry experiences unprecedented changes at a stunning pace
- Significant supply side changes that include continued rapid growth of renewables and changes in our thermal power generation mix may lead to changes in markets, system operations, and system planning
- New consumers and new technologies may alter our demand situation significantly and lead to more uncertainty in demand forecasts
- Smart grid offers both opportunities and challenges
- New approaches to data management, analysis, and modeling will be needed

Questions?

THANK YOU!

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