Research Centers

Mohammad Shahidepour – IIT/Robert Galvin Center for Electricity Innovation
“Microgrids for promoting higher resilience, security, reliability and economics in Smart Cities”

Jack Brouwer – University of California, Irvine - Advanced Power and Energy Program
“Design, Control and Integration of Next Generation Power and Energy Systems”

YiXing Chen – Lawrence Berkley National Lab
“City Building Energy Saver (CityBES): A web-based platform to support city-scale building Energy Efficiency”
Microgrids for Promoting Higher Resilience, Security, Reliability and Economics in Smart Cities

Mohammad Shahidehpour, IEEE Fellow
Galvin Center for Electricity Innovation
Illinois Institute of Technology
IIT Microgrid is located 2.5 miles south of downtown of Chicago and is bounded by major streets, highways, and railroads.

- Funded by the Department of Energy
- Located at IIT
- Covers the entire campus
DSO as a Partner to Microgrids / Prosumers
Community Microgrid In Chicago

Technology Product and Testing Providers

Technology Developers

Project Lead & Electric Utility
Key Technology: Microgrid Controller

ComEd (Master Controller for Microgrid)

Bronzeville Community Microgrid (BCM Physical System)

Database and Solution Platform Providers

Bronzeville Community Microgrid (BCM Design Model)
Retail and Wholesale Operations
Smart Cities

- **Smart meters** on every home and building give residents and the utility invaluable two-way information about energy use, leading to greater efficiency, improved reliability and cost savings.

- **Intelligent Transportation Systems** which use a two-state optimization for reducing emission, fuel usage, and travel time.

- **Smart grid and Alternative energy** enhance economics and reduces the need for fossil-fuel generation.

- **Physical and Cyber Security in Communications network** that connects smart meters can often be used for other city purposes.

- **Microgrids and resilient systems** can execute protection schemes in microseconds, minimizing outages.

- **DSO, fast switches and automated outage management** detect disturbances and isolates areas before they create a cascading blackout.

- **Sensors, visualization and analytics** provide situational awareness of what is going on with electric power, natural gas, communication, water, and transportation systems.

- **Electrical vehicles and regenerative braking** reduce fossil fuel consumption and increase energy independence. They can fortify the grid and increase the integration of renewable energy.
Smart City Infrastructures

- Water
- Transportation
- Oil
- Natural Gas
- Electric Power
- Telecom
Design, Control & Integration of Next Generation Power & Energy Systems

for: Utility of the Future and Energy Innovation Workshop @ Rutgers University
NFCRC Work and Associated Experience

- Fundamental and applied research for developing and understanding fuel cell systems science, integrated systems development and application to the built environment and vehicles
  - Emphasis on high temperature fuel cells
  - Integrated system development for all fuel cell types
  - Stationary fuel cell systems and infrastructure
  - Experimental and numerical
- Recognized Expertise in:
  - Fuel Cell Dynamics and Control
  - Cycle Conceptualization and Analyses
  - Fuel Cell Integration with Gas Turbines
  - Built Environment Integration
  - Fuel Cell and Plug-in Hybrid Vehicle Testing and Analyses
  - Renewable Fuel Cells
  - Hydrogen Infrastructure Development and Evaluation
  - Stationary Fuel Cells
- Education and Outreach
  - First U.S. University Graduate Fuel Cell Course (2001)
  - Short courses (FC Seminar, ICEPAG, FCTI)
  - California Stationary Fuel Cell Collaborative
Renewable Tri-Generation of Power, Heat & H₂

First application:
- Orange County Sanitation District
- Euclid Exit, I405, Fountain Valley
- Support: DOE, ARB, AQMD
- December 2010

Diagram elements:
- Sludge
- Storage tank
- Heat exchanger
- Digester
- Anaerobic digestion gas holder
- ADG
- Hydrogen storage
- Hydrogen dispenser
- Fuel cell
- Fuel treatment
- Boiler
- AC power
- Hot water

Logos:
- Advanced Power and Energy Program
- National Fuel Cell Research Center
- University of California, Irvine
- Air Products
- FuelCell Energy

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Sample Dynamic Simulation Module Geometries

• Planar SOFC with 10 Discrete Computational Nodes
  o Anode Gas, Cathode Gas, Cell EEA, Separator Plates

  ![Diagram of Planar SOFC with 10 Nodes]

  - REFORMED FUEL
  - CATHODE GAS
  - CELL EEA
  - SEPERATOR PLATE

• Reformer Module with 5 Discrete Computational Nodes
  o Anode Off-Gas Recycle, Fuel Mix, Combustor HX, Catalyst Bed

  ![Diagram of Reformer Module with 5 Nodes]

  - EXHAUST
  - NATURAL GAS
  - Adiabatic Mixing Volume
  - Catalyst Bed

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Dynamic Simulation: 220kW SOFC/GT System

SOFC Power Experimental and Model Comparison for the 220 kW SOFC/GT Hybrid

- Model SOFC Power
- Experimental SOFC Power
- SOFC Fuel Flow
- Recuperator Bypass Valve
- SOFC Bypass Valve

SOFC Power (kW) and Fuel Flow SLPM*(0.30)

Time (sec)
Renewable Fuel Cell Systems Research

Utility Grid → Electrolyzer → Photo-voltaic System

Hydrogen Storage

Fuel Cell → Inverter → Computer/Loads

Data Acquisition
Renewable Fuel Cell Systems Research

4.2 kW RFC Supply & Demand Power Flow:

<table>
<thead>
<tr>
<th></th>
<th>PV Power</th>
<th>7.9 kW EZ Power (In)</th>
<th>4.2 kW FC Power (Out)</th>
<th>Grid Power</th>
</tr>
</thead>
</table>

- **System Cost**: $42,000.00
- **H2 Produced**: 50.9 kWh
- **kW Peak RFC**: 8.1 kW
- **RFC Round Trip Eff.**: 57%
- **System Eff.**: 71%

18-mile weekday commute
Renewable Power Systems Research

- Energy Deployment Model Results - 33% Wind Penetration
Power-to-Gas – UCI Microgrid

APEP/NFCRC
6kW Electrolyzer
First H₂ Pipeline Injection

Small Electrolyzer

Thermal Storage
4,500,000 Gal
60,000 Ton-Hour

Large Electrolyzer

UCI Substation

Central Plant:
8 chillers
Gas turbine: 13.5 MW
Steam turbine: 5.5 MW

Edison MacArthur Substation

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• P2G could significantly increase renewable percentage at UCI.

34.16 MW of Solar Power
Max H₂ allowed: 15%
Electrolyzer size: 26.67 MW
Power-to-Gas – UCI Microgrid Use Model

- P2G could significantly increase renewable percentage at UCI

- Renewable Energy Integration! 35.31%

- 34.16 MW of Solar Power
  Max H₂ allowed: 15 %

- Electrolyzer size: 26.67 MW
  February 11 and 12, 2015
Smart Grids & Microgrids
Irvine Smart Grid Demonstration (ISGD)
Irvine Smart Grid Demonstration (ISGD)
Irvine Smart Grid Demonstration (ISGD)

- Solar Car Shade with Battery Energy Storage System
Emerging Energy Storage Dynamics

- Compressed Hydrogen Storage complements Wind & Power Demand Dynamics

- Load shifting from high wind days to low wind days
- Ideally, excess wind energy (blue) is captured for later use (red)

Emerging Energy Storage Dynamics

- Weekly storage and seasonal storage possible with hydrogen and fuel cells/electrolyzers

City Building Energy Saver (CityBES):
A Web-based Platform to Support City-Scale
Building Energy Efficiency

Tianzhen Hong, Yixing Chen,
Sang Hoon Lee, Mary Ann Piette

Building Technology and Urban Systems Division

Utility of Future, Rutgers University
September 16, 2016
How to reduce 50% energy use in city building stock?

- Buildings in cities consume about 30% to 70% of total primary energy
- Cities have different energy use profiles for buildings
- Buildings sector has the most potential to save energy
- An integrated data and computing platform is needed
CityBES

**Filtering Buildings**

**3D + GIS + Color Coding**

**Building Highlight**

**Aggregated Retrofit Results**

- **Filtering Buildings**
- **3D + GIS + Color Coding**
- **Building Highlight**
- **Aggregated Retrofit Results**
Overview of CityBES

◆ Scenario analysis supporting city energy efficiency programs
  ▪ Evaluation and prioritizing building energy retrofit opportunities
  ▪ Impacts of climate change / heat waves
  ▪ Urban energy planning
  ▪ City buildings energy benchmarking
  ▪ Potential of renewable energy
  ▪ Advanced district energy systems

◆ Detailed modeling and simulation
  ▪ Urban buildings, considering interactions with urban climate, transportation, socio-economic.

◆ Builds upon open standards
  ▪ CityGML: An international OGC standard for representation and exchange of 3D city models.
CityBES Software Architecture

**DATA**
- Weather Data
- Building Stock
- GIS
- Database (building technologies, utility data, etc.)

**ALGORITHMS, SOFTWARE**
- EnergyPlus Simulation Engine
- OpenStudio SDK
- CityGML (3D City Models)
- CityBES

**USE CASES**
- Energy Benchmarking: To compare energy use among peers
- Urban Energy Planning: To provide best strategies for energy systems
- Energy Retrofit Analysis: To support retrofit decisions for city policy makers
- Building Operations: To improve operations of city building stock

**VIZUALIZATION OF PERFORMANCE**
Challenges

- **Data**: A big data problem integrating diverse sources with different temporal and spatial resolutions, quality, and structure/format.

- **Modeling**: Integration of multiple domain models with different scales and resolutions, using open standards.

- **Simulation**: An exascale computing problem: $10^6$ bldgs, $10^{13}$ FLOP/bldg, 10 interconnections, $10^2$ scenarios; run in 3 hours.
Thank You

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CityBES.lbl.gov
Introduction of CityGML

- An international OGC standard for representation and exchange of 3D city models.
- Defines 3D geometry, topology, semantics and appearance of urban objects
- History: Started in 2002 by SIG 3D, version 1.0 in 2008, version 2.0 in 2012
- Provides multi-resolution model at various LODs (Level of Details)
- Customization and extensibility
  - User defined groups of aggregations
  - Extensible with Application Domain Extension (ADE) or the Generics module
CityGML Representation of Buildings

Five levels of details:

- **LOD0** – footprint at ground or roof level
- **LOD1** – block
- **LOD2** – roofs, walls, floors
- **LOD3** – + openings, shades
- **LOD4** – + interior spaces

*Fig. 3. Five Levels-of-Detail (LoD) provided by CityGML (images: KIT Karlsruhe, K.-H. Häfele, Gröger et al., 2012).*
CityGML Applications

- Urban planning (land use, transportation)
- Disaster management – fire, flood
- Emergency response – indoor navigation
- Energy assessment
- Facility management
- Noise propagation and mapping
- Urban micro climate
- Urban air quality

By T. H. Kolbe
Integration of City Building Data
(San Francisco as an example)

Data (source)
- Building Footprint (SF GSA Technology)
- Land Use (SF Planning)
- Parcel Data (CoStar Group)
- Energy Ordinance (SF Environment)
  - Clean up and create unique building IDs (SF)
  - Consolidate (LBNL)

Processing
- Building ID
- Parcel Number (APN)
  - Mapping

Products
- Comprehensive Building Dataset
  - (e.g., GeoJSON, CityGML, Shapefile)
  - Merge

Applications
- CityBES (LBNL)
- BRICR (BayREN, DOE Project)
- DECAF (NREL)

Extra Data Sources
- Building Permit (SF Building Inspection)
- Energy Watch Program (SF Environment)