Smart Energy Campus

A Smart Grid Test Bed for Advanced Modeling, Simulation and Decision-Making
ECE Research Group

Smart Energy Campus Project Team

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Objective:
The test bed has been built to explore various possibilities for the future smart grid in order to
- improve system reliability,
- enhance system capacity to host renewable energy, and
- allow interactions between energy providers and consumers.

The smart energy campus
is a living smart grid test-bed of Georgia Tech, which
- Covers 200 buildings and
- Has more than 400 smart meters,
- 3 years of AMI data (15 minutes resolution),
- State-of-the-art IT system for data collection and management
Outline

- Data Management
  - AMI data management
  - GIS data integration
  - Robust distribution system state estimation

- Advanced Load Modeling
  - Roof-top solar systems
  - Electric vehicles
  - Time-variant load modeling

- Long Term Planning
  - Campus renovation and expansion
  - Shuttle electrification
  - Energy Storage

- Visualization

- Demand Response & Real-time Pricing
AMI Data Management

- Smart meters
  - Installed in more than 200 buildings
  - 400 main meters and sub-meters
  - Real-time data acquisition

- Historical database
  - ION database (facility)
  - SQLite database (research)

- Data Access
  - API request (upon authorization)
  - Web-based dashboard through desktop or smart phone
  - Interactive visualization (Java-based)
Robust Distribution System State Estimation
Advanced Load Modeling

- Roof-top Solar Systems
- Electrical Vehicle Charging Load
- Time-variant Load Model
Load Modeling: Solar Photovoltaic

- Three roof-top PV systems:
  - Campus Recreation Center (CRC)
  - Carbon Neutral Energy Solutions Laboratory (CNES)
  - Clough Undergraduate Learning Commons (Clough)
- CRC PV array was installed in 1996, which was one of the largest roof-mounted PV system.
- Continuous monitoring cumulate valuable data.
Load Modeling: Electric Vehicles

- Steady growth of EV charging demand:
  - As of Feb. 2014, there were 155 EVs on campus.
  - EV type: Leaf 90%, Tesla, BMW i3...

- Charging Infrastructure
  - Three Level I charging stations
  - Six Level II charging stations

- A statistic model for EV charging demand has been developed
Load Modeling: Electric Vehicle

**Objective:**
we seek to model the PHEV charging behavior through a $M_t/G/\infty/N_{max}$ queue with finite calling population

- $M_t$ means the periodic non-homogeneous arrival rate is a function of time $t$;
- $G$ stands for the empirical distribution of PHEV charging duration;
- $\infty$ means the charging system is a self-serve system with no waiting time;
- $N_{max}$ is the total number of PHEVs, which is known.
According to the central limit theorem, we could construct the confidence interval for the long run average mean values, which follows the $t$ distribution. **Conclusion**: The actual charging intensity coefficient is around 0.25.
The vast deployment of smart meters producing massive amount of data and information yet unexplored

Load Model Definition

\[ P = P(V) \quad Q = Q(V) \]

Current load modeling methods

- Component-based approach
- Measurement-based approach

Hence, we propose a time-variant load model based on smart meter historical data
Load Modeling: Time-variant Model

• The Load Condition Assumption

It is possible to create a load model through data-mining processes.

• Data Mining Technologies

![Data Filtering](image1)

![KL divergence](image2)

![K-subspace Method](image3)

![Cluster Evaluation](image4)

Voltage Deviations

Customer Behaviors

$\Delta P$ and $\Delta Q$ in smart Meter Readings
Long-term Planning

- Campus Renovation and Expansion
- Shuttle Electrification
- Energy Storage
Objective:
Optimize the distribution system in order to meet the campus future needs.

Solution:
- Estimate campus future needs
  - Natural load growth
  - New buildings and expansions
  - Location of new loads
- Simulate the future scenarios through integrated simulation environment
  - Pin the new loads through google earth.
  - Incorporate new system components to the OpenDSS model, such as new transformers, secondary lines.
  - Serving new load with new feeders or existing feeders.
  - Check system reliability.
Future Campus Renovation & Expansion

Campus Total Load (kW)

Project Completion Time Line

EBB1

EBB2

EBB3

"Laminated" Bldg

West Campus Dining Hall

Ferst Center

Library

Project Location Map
Shuttle Electrification

**Objective:**
Upgrading the current diesel shuttles with electric buses, while maintaining current services.

**Solution:**
- Replacing 23 existing buses with 23 electric buses ($900K/unit)
- Charging Infrastructure:
  - 2 fast chargers ($600K/unit)
  - 10 stop chargers ($70K/unit)
- Lithium titanate battery (6 years)
Shuttle Electrification

Breakdown of total NPV cost

$24.1M
$12.6M
$11.5M

56% INITIAL COST

Diesel
Electric

- Battery
- Maintenance
- Fuel cost
- Charging equipment
- Bus purchase price

Million $
**Energy Storage**

**Objective:**
Estimate the feasibility of introducing energy storage systems on campus.

**Solution:**
- NaS Battery (Sodium-Sulfur Battery)
  - Battery life (up to 13 years)
  - Efficiency: 78% (including PCS efficiency 95%)
- Fixed costs
  - Battery long-term cost ($250/kWh)
  - Power Conversion System ($150~$260/kW)
  - Balance of Plant ($100/kW)
- Operation and Management Costs
  - Fixed O&M cost ($0.46/kW-year)
  - Variable O&M costs: ($0.7 cents/kWh)
Energy Storage

Energy Storage Control Optimization:

Objective:

- Minimize total cost:
  - Fixed cost along the battery life
  - O&M cost
  - Charging Cost
  - Discharging revenue

- Constraints:
  - DOD or Battery capacity
  - Efficiency
  - Peak charging/discharging rate

Loss 26$/day for a System with 100kWh Capacity
Visualization

- Enhance situational awareness
- Expose consumer behaviors
- Encourage building-to-grid interactions
Test Bed Distribution System Over View
Situational Awareness

Bird’s-eye View of the Campus Energy Consumption
Situational Awareness

Building Energy Consumption Intensity Log
Real Time Pricing

- The test bed campus is served under “Real Time Pricing – Hour Ahead Schedule” (PTR-HA) tariff provided by Georgia Power.

\[ Total.\ Bill = Std.\ Bill + RTP.\ Bill \]

where \( RTP.\ Bill = \sum_{hr} RTP.\ Price \times (Load - CBL) \)

- Customer baseline load (CBL) is developed for the test bed according to the energy consumption of the test bed from the previous calendar year.
Demand Response Applications

- Metasys Software is used to integrate and control chillers based on price signals
  
  **Demand Response Inputs**
  - Real-time energy consumption
  - HAVC system setting
  - Chiller plant condition
  - Real-time price signals

  **Demand Response Outputs**
  - Update HAVC setting
  - Chiller plant control
Thank you !