Future Distribution Systems: Challenges and Opportunities

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Power Distribution Networks

Highly interconnected, interdependent and complex networks. Prone to disturbances:

- Primary – Environmental, equipment malfunctions, loads…
- Secondary – Protection mechanisms, operator initiated controls, …

No global stability regimes, inter-area behaviors
Seasonal, weather induced, and circadian variations
Incomplete observability

Future systems:

- Increased sensing and data analytics
- Command, communications and control
- Dynamic tracking of system operating state
- Managing highly distributed and diverse generation/load mix
- Improved operational readiness, reliability and resilience
Anatomy of the Grid
Today’s Distribution System

- Primarily radial network
- Power flow from substation to end users
- Limited Distributed Generation
- Limited Demand Response
- Flat rate tariff
A Transformation is Occurring

- Plumbing to internet
- Central to distributed & intermittent
- Predictable loads to smart buildings & customer intervention
Vision for Tomorrow: A smart and connected energy ecosystem

- Renewable energy
- Real-time rates
- Power plants
- Factories
- Electric vehicle recharging
- Buildings
- Homes
- Intelligent homes
- Grafting IT on power grids
Future Vision

- Active control of edge devices
- Distributed Energy Resources (generation and storage)
- Data analytics for monitoring, control and optimization
- Reactive and Transactive control architectures that integrate behind the meter customer assets with distribution system operations
- Real-time control and decision-making for integrated distribution system operation
Future Distribution System
(Efficient, Reliable, Resilient)

- Coordinated network operations
- Bidirectional power flow from end users back to bulk grid
- Distributed Energy Resource integration
- Demand Response
- Market tariff (dynamic rates)
- Microgrids that form self-sufficient electrical islands
Challenges

– Customer engagement
– Wide range of time scales
– Geographical distribution of assets
– Dynamic system state
– Reliability and resiliency
– Number of nodes
– Security
Opportunity: Transactive Energy

Self-configuring, self-commissioning and self-learning buildings will optimize operation to maximize energy efficiency and participate in transactions within the building, between buildings, and coordinated with distribution system operations.
Hypothesis: The financial viability of building efficiency may be suboptimized since margins are thin. Grid integration (i.e., demand response) alone is not financially viable in many instances, BUT... a model with multiple transactions within the energy ecosystem enhances the value proposition.
Conceptual Framework of Transactive Controls

(Courtesy of “Simulation Models for Evaluation of Network Design and Hierarchical Transactive Control Mechanisms in Smart Grids” by D. Jin, X. Zhang, and S. Ghosh.)
DOE SHINES: Beneficial Integration of Energy Storage and Load Management with PV

Objective: *Beneficial Integration* of solar photovoltaic generation and advanced forecasting, load management, and energy storage to create dispatchable renewable distributed generation at minimized cost

Approach: Design, develop, and demonstrate a two-level control architecture including: *System controller* that maintains wide area reliability and power quality through coordinated control of multiple local controllers and other distribution equipment; *Local Controller* that converts solar PV generation to a dispatchable resource through efficient utilization of energy storage, controllable load, smart inverters, and solar/load forecasting and responding to system controller needs to achieve overall system benefits
**Project Overview**

**Approach**
- Control architecture
- Functional requirements
- Performance metrics

**System Design & Implementation**
- Local & system controllers
- Smart inverter design & development
- Improved solar forecasting module

**Demonstrations**
- Site preparations
- PV & ESS Commission
- Data collection

**Performance Assessment & Impact Analysis**
- Solution technical performance
- Impact on PV hosting capacity
- Cost & benefit analysis

**Collaborators:**
- EPRI
- EATON
- GE Grid
- LG Chem
- FirstEnergy
- **Local controller** sends available DER capability information to system controller.
- **System controller** sends real and reactive power setpoints to local controller.
University of Toledo & JCI
- Assets: 6 controllable buildings, EV, storage, 1 MW PV, 80 kW wind
- Objective: Multi-asset management/transaction-high reliance on PV
- Yr 1: PV + building + battery

NASA
- Assets: Large, highly variable loads and controllable buildings
- Objective: Manage large load variations through transactions with buildings
- Yr 1: distr. sys. Modeling

CWRU & Eaton
- Assets: Controllable buildings/storage, 100 kW wind
- Objective: Multi-asset management and transactions on a campus
- Yr 1: buildings + battery
CWRU Central Stream and Chilled Water Supply

Central district energy provider: Supplies steam, chilled water, and electricity.
Building Loads: Olin Building Air Handler Unit

(Olin has one central air handler with an economizer managing the mix of return air and outdoor air.)
Building Loads: Olin Building Thermal Zones

C.W.R.U. Olin Building - Third Floor
Outside Air Temperature - 62.65 °F

(Each of the 8 floors in Olin building are further divided into Thermal zones.)
• DoE/PNNL Demonstration Project

• Objective-use energy storage and load control to flatten load observed by campus
  
  – 40kW variation due to labs/HVAC
NASA GRC Distribution System

- Complex electrical network-voltage levels ranging from 138kV to 2.4kV.
- Base demand ~20MW with peak demand ~250MW
- 100 buildings located on the campus
- System supports five large loads that can be controlled to achieve more balanced load operation
NASA Experiments

• Demonstrate the impact of enabling Load Assets, including buildings, to manage energy demand variability
• Demonstrate the impact of enabling Load Demand to manage energy demand variability
• Demonstrate the effectiveness of integrative (reactive and transactive) control, e.g. using VOLTRRON to managing all building through controllability of individual devices to optimize loads, as well as agent-based optimization within and amongst buildings to coordinate and manage the supply/demand for overall system optimization response needs.
• Demonstrate supporting Grid Ancillary Service Levels using large variable motor-loads, representing an industrial campus to evaluate impact on both hi- and med-voltage grid network operations
• Transactive Control as an enabling technology to manage, coordinate and prioritize building equipment, devices and resources including: HVAC, steam, chilled water, voltage, current, mw demand, etc.; hi/med-voltage distribution network, ABS DCS, and Siemens BAS
NASA Glenn Buildings to Grid Integration

Building to Grid Integration Demonstration
Conceptual Control Architecture at NASA Glenn

- Siemens MGMS
  - VOLTRON Adapter
    - MGMS Proxy Agent
- ABB DCS
  - Existing Interface
  - Measurements from Meters
  - Existing Interface
  - Measurements from Meters
  - Existing Interface
  - Controllable Building Loads
- VOLTRON
  - Distributor company Agent
  - Energy Market Agent
  - Weather Agent
  - Application Agent

Existing Interface

Controllable Devices