Transactive Energy: Coordination Strategies for Enabling DERs to Provide Grid Services

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Outline

➢ Background and Motivation

➢ Transactive Energy

➢ TE: Enabling Different Coordination Architectures
  ▪ Prosumer-to-Grid
  ▪ Community-based

➢ TE during Emergency Conditions

➢ Modeling Capabilities

➢ Summary
Background: Power System Economics

➢ Conventional Electricity Markets
  ▪ Hierarchical top-down approach
  ▪ Optimal resource allocation and pricing

➢ Electric landscape is undergoing significant changes
  ▪ Proliferation of renewable energy resources (declines in cost)
  ▪ Increasingly savvy prosumers

Source: https://www.eia.gov/todayinenergy/detail.php?id=30692
Changing Landscape: Distribution System Operator

➢ Distribution System Operator
  ▪ Operational:
    ▪ Limited to no visibility or control
  ▪ Business:
    ▪ Reduction in the utility’s net energy sales
    ▪ Increased costs - variability and unpredictability

Source: www.finanzen.net

Share Price of selected German Utilities vs. DAX 2006-2015

Source: https://climatetechvc.substack.com/p/lessons-from-plaid-for-a-future
Customers: Consumers to Prosumers

➢ Consumers into “prosumers”
  ▪ Increasing awareness coupled with decline in cost
  ▪ Favorable regulations
  ▪ Advancement of ICT and HEM

➢ Prosumers
  ▪ Proactively manage their underlying DERs

➢ Consumer-centric economies:
  ▪ Cloud based operations for distributed systems
  ▪ Blockchain for decentralized mechanisms

➢ FERC Order 2222
  ▪ Enables DERs to participate in the regional organized wholesale markets through aggregations.
Transactive Energy

“A system of economic and control mechanisms that allows the dynamic balance of supply and demand across the entire electrical infrastructure using value as a key operational parameter.”

➢ Orchestrating the coordinated operation of DERs

➢ Provides market-based mechanisms
  ▪ Integrating DERs to participate in the electricity markets
  ▪ Achieved through device-specific intelligent agents

➢ Effectiveness of TE system have illustrated through
  ▪ Several field demonstration
  ▪ Several co-simulation frameworks

Implementing TE systems for customer coordination.
Future consumer-centric coordination envisages structured organization:

- **Prosumer to Grid**
  - Prosumers actively participate in market
  - Centralized – moderated through aggregators/LSE

- **Organized Prosumer Groups (Community Based)**
  - Group of prosumers pools resources
  - Decentralized – Transact energy with other communities/DSO

- **Peer-to-peer**
  - Directly interconnect with each other, trading energy services
  - Fully Decentralized

Fig. Structural attributes of prosumer markets: Prosumer-to-grid, organized prosumer group, peer-to-peer models.
Prosumer-to-Grid Coordination: Hierarchical Architecture

Fig: TE architecture for Prosumers-to-Grid Coordination

Fig: Model architecture of the proposed incentive-based control mechanism
Prosumer-to-Grid Coordination: DER Integration and Dispatch Strategy

Device level

Feeder level

Substation level

Device level

Feeder level

Substation level
Why Integrated T&D simulations ?

➢ Comparison of price-responsive only (one-way) vs bidding (two-way) transactive control

➢ Transmission system model of WECC in MATPOWER connected to distribution circuits in GLD with 25% controllable load.

➢ Results show one-way control can produce oscillations while two-way does not.

Prosumer-to-Grid Coordination: Co-simulation & Use-Case

Price-priority dispatch of flexible loads

Fig. WECC 240 network topology showing the modeled bus, transmission lines, and modeled outdoor air temperatures.
Prosumer-to-Grid Coordination: Demonstration

Fig. WECC 240 network topology showing typical feeder demand at different locations.

Bus at Montana

Bus at Arizona

Fig. Combined load of the all buses connected to the WECC-240 system (ISO Level)
Key Learnings

➢ TE Concepts
  ▪ Cobweb effect on decoupled implementations
  ▪ Spatial Variation of flexibility

➢ Software Skillsets
  ▪ Distribution System Simulator
    o End-user load modelling
    o Thermostatic loads
  ▪ Co-simulation Tool
    o Framework for Network Co-simulation (FNCS)
  ▪ Wholesale Market Emulation
    o MATPOWER/PYPOWER
  ▪ High Performance Computers
    o SLURM scripting
Community-Based Coordination

➢ Community Based Markets
  ▪ Group of smart consumers (prosumers) pools resources
  ▪ Transactive Communities (TC)
    ▪ Distributed transactions with TCs/DSO
  ▪ Simplified interface to existing market constructs

➢ Evaluate stakeholders benefits & market feasibility
  ▪ Prosumers
    o Owning DG or demand-side DERs
  ▪ Community Manager
    o Cumulative flexibilities of the TCs
    o Allocation and prices from the community market
      \( \lambda_{CM_k}^{Cleared} \) & \( Q_{CM_k}^{Cleared} \)
  ▪ DSO - Electricity Price & surplus capacity

Fig: Overview of the coordination architecture
Community-Based Coordination

➢ Development of consensus-based transactive mechanism
  ▪ Distributed optimal dispatch of price-responsive load and generation
    \[
    \text{Max. SW} = - \sum_{T=0}^{N_T} \sum_{K=1}^{N_K} C_{k,t} \left( Q_{k,t} \right) : e \in \{ T_{C_1} \ldots T_{C_N} \cup DSO \}
    \]
    \[\text{S.T.} \sum_{K=1}^{N_K} Q_{k,t} = 0 \quad \forall \ t \in (0,24)\]
    \[Q_{k,t}^{\text{min}} \leq Q_{k,t} \leq Q_{k,t}^{\text{max}}, \Delta Q_{k,t}^{\text{lower}} \leq \Delta Q_{k,t} \leq \Delta Q_{k,t}^{\text{upper}}\]
  ▪ Implementation of both **DA and RT** retail energy markets

➢ Distributed Optimization and Co-Simulation
  ▪ Modeling communication between different participants using HELICS
    o HELICS Publications & Inputs: Between the DERs (GridLAB-D) and TC (Python) during bidding and dispatch
    o HELICS Endpoints: Between the Transactive Communities (in Python) and DSO (in Python), during iterative market clearing.
    o HELICS Filters: To emulate asynchronous communication delays during iterative market clearing modeled using bounded uniform distributions

Community-Based Coordination

Key Learnings

➢ TE Concepts
  - Consensus-based distributed coordination
  - Impacts on asynchronous communication systems
  - Potential Impacts on Wholesale Markets at higher penetrations (ongoing effort)

➢ Software Skillsets
  - Distribution System Simulator
    - End-user load modelling
    - Thermostatic loads
  - Co-simulation Tool
    - Hierarchical Engine for Large-scale Infrastructure Co-Simulation (HELICS)
Transactive Energy During Emergency Conditions

➢ Extreme Events – Extreme Outages
  ▪ Major modern-day concerns of utilities is dealing with extreme outages and consequently, its repercussions on the lives of people in society and social aspects

Fig. California consumers respond to text-alerts during heat wave

Transactive Emergency Power Allocation

➢ Text Alerts
  ▪ Situational awareness to customers
  ▪ No guarantees to avoid widespread outages

➢ Rolling Blackouts:
  ▪ Lower-priority customers have high-priority loads (i.e., refrigeration, telecom., etc) that should also be serviced (if at all possible)

➢ Energy/Power Allocation
  ▪ Customers be provided with energy allocation
  ▪ How can allocation be effectively implemented for electrical energy systems?

Fig. ERCOT market Prices during Texas Freeze events
Transactive Emergency Power Allocation Mechanism

Device Controllers

Dispatch Devices

Price

Allocation for Sale

Allocation to buy

Price

Allocation to buy

Allocation for Sale

Price

Device Controllers

Device Controllers

Device State, Q_device

Setpoints, Status (ON/OFF)

Comfort (Slider = 1)

Savings (Slider = 0)

Q allocation

Q allocation

Q allocation

Quantity

Quantity

Quantity

Price

Price

Price

DSO

Supply Bid / Demand Bid

P_auction, Q_auction

P_allocation, Q_allocation

DSO

Dispatch  Devices

Transactive Emergency Power Allocation Mechanism

Mechanism

Ph.D. Student

Internship

DGRP

S&E Career
Proof-of-Concept Demo

Fig. Test system - Prototypical feeder R4-25.00-1.

Fig. Impact of the TEPA on Feeder demand
Modeling Distribution Grid Response: DSO+T Study on ERCOT

DSO+T Study: https://www.pnnl.gov/projects/transactive-systems-program/dsot-study

Modeling Distribution Grid Response: During Extreme Weather Conditions

Fig. 8-Node Model of ERCOT region

Transactive Systems Program

Modeling Distribution Grid Response: VT (ISO-NE)

Fig. ISO NE Load Zones

Fig. Distribution Utilities at the VT-Load zones
Wholesale Market Emulation

➢ **MATPOWER + MATPOWER Optimal Scheduling Tool (MOST)**
  - AC Power Flow: Determine system states for bulk power systems
  - Deterministic OPF for Single period & Multi Period: DA & RT Markets
  - Stochastic DC OPF to account for renewable uncertainty
  - Dispatchable Demand: Facilities DSO Bidding
  - Grid Scale Storage

➢ Integration using HELICS based MOST Wrapper
  - HELICS based Communication between ISO $\leftarrow$ DSO
    - System states between the T&D Systems
    - Market States between DSO and ISO.
  - Translation of (DA and RT) bids from DSO to equivalent representation inside Matpower objects for simulating OPFs.

Code base: [https://github.com/GMLC-TDC/MATPOWER-wrapper](https://github.com/GMLC-TDC/MATPOWER-wrapper)
Wholesale Market Emulation

Fig. Actual Generation Mix of ERCOT for Aug 2016

Fig. Simulated Generation Mix of ERCOT for Aug 2016

Fig. Impact of Flexibility on Unit Commitment Decisions

Fig. Variation of DA and RT Prices for different Flexibilities at Bus 2
Summary

The Use-cases presents different flavors of how Transactive Energy can

➢ Effectively enable DERs to through different Coordination Architectures
  ▪ Prosumer-to-Grid
  ▪ Community-based Coordination

➢ Effectively enable customers to provide different Grid Services
  ▪ Congestion Management (Peak load Reduction)
  ▪ Emergency Support (Emergency load reduction support)

➢ Simulation Support for TE systems
  ▪ Distribution Grid Response Modelling
  ▪ Wholesale Electricity Market Emulation
  ▪ Key Resources for users:
    o Transactive Energy Simulation Platform: [https://github.com/pnnl/tesp](https://github.com/pnnl/tesp)
    o MATPOWER-Wrapper: [https://github.com/GMLC-TDC/MATPOWER-wrapper](https://github.com/GMLC-TDC/MATPOWER-wrapper)
Thank you