Customer-Oriented Planning Strategies for Active Distribution Systems

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North Carolina State University

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Clemson University
# Project Team

## Clemson Team

<table>
<thead>
<tr>
<th>Role</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faculty Advisor</td>
<td>Dr. Ramtin Hadidi &amp; Dr. Jesse Leonard</td>
</tr>
<tr>
<td>Undergraduate Students</td>
<td>Joshua Smith, Jeffrey Miller, Garrett Bacon</td>
</tr>
<tr>
<td>Graduate Student</td>
<td>Roghieh Abdollahi</td>
</tr>
</tbody>
</table>

## NCSU Team

<table>
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<tr>
<td>Faculty Advisor</td>
<td>Dr. David Lubkeman &amp; Dr. Ning Lu</td>
</tr>
<tr>
<td>Undergraduate Students</td>
<td>Taylor Hill, Lilly Vang</td>
</tr>
<tr>
<td>Affiliated Graduate Student</td>
<td>Catie McEntee, David Mulcahy, Lisha Sun, Jiyu Wang, Asmaa Alrushoud, Ahmed Mohamed</td>
</tr>
</tbody>
</table>
Project Overview

✓ Current situation
Current approach to distribution planning somewhat **utility-oriented** in that it assumes utility owns and operates most generation and customers are passive participants.

✓ New Technology and Market Initiatives
In the future, customers owning distributed energy resources (DER) will result in an “active” distribution system, requiring new planning paradigms, with more focus on customer benefits and participation in the local energy market.

✓ Proposed Project
This project aims to develop **customer-oriented** planning strategies for active distribution systems that incorporate customers’ expectations and future grid impacts.
Project Benefits

• Establish both customer-oriented and utility-oriented planning model.
• Develop continuous power flow calculation methods and model dynamic responses of the active distribution system.
• Develop new active distribution system planning criteria.
  ❖ Integration of smart PV inverters
  ❖ Integration of energy storages
  ❖ Integration of demand response resources
Work Plan

Task 1: Identify features relevant to CAPER membership
Task 2: Define use case scenarios and architecture assumptions
Task 3: Build a test bed
Task 4: Develop models for customer-owned/operated DER and demand response
Task 5: Construct power flow/dynamic analysis methodology
Task 6: Characterize customer-oriented applications
Task 7: Planning criteria for customer-oriented distribution
Task 1 – Identify Features

Define features of future customer-oriented active distribution systems

- Extract features from customer-oriented distribution systems considered in other part of the grids (New York, California, and Hawaii)

- Review European and other non-US customer-oriented planning initiatives

- Get Duke Energy’s and other CAPER participant feedback on which features should be considered in this study
Jan 27 Discussion with Duke Energy

- Duke Energy has several existing and past initiatives we could possibly get data from: Zero Energy House EPRI project, Duke Energy circuit with AMI data, possibly data collected for rate analysis.
- Duke Energy has issues modeling load with distributed generation. Limited ability to “disaggregate” to determine impact of the DG component.
- Duke Energy is currently evaluating storage technologies. However, there is currently no energy storage tariff.
- Would be value in looking at scenarios and business case for utility vs. customer owned storage. Work on evaluating tariff options ranging from flat rate to dynamic pricing structures.
Presentation Outline

• Introduction    - Dr. David Lubkeman
• Ongoing Initiatives
  – NY REV, Northeast - Catie McEntee
  – CA & HI vs. Duke Energy - Roghieh Abdollahi
• Analytical Modelling Tools Survey
  – HOMER - Taylor Hill
  – OpenDSS - Joshua Smith
  – GridLAB-D - Lisha Sun
• Customer Modeling    - David Mulcahy
• Conclusions – Dr. Ramtin Hadidi
Literature Review:
Initiatives in the Northeast

Catie McEntee
Northeastern Energy Markets

• Deregulated
• ISOs
• Higher Prices

While the industry landscape is different, we can learn from their projects

https://www.electricchoice.com/map-deregulated-energy-markets/
Initiatives in the Northeast

**NY REV** directs utilities to create markets for distribution services provided by distributed generation (DG), demand response (DR) and energy storage (ES).

Affects Consolidated Edison, National Grid, Central Hudson, Iberdrola, Orange & Rockland

**Massachusetts Energy Storage Initiative** aims to incorporate ES into the state’s energy portfolio by creating a market for ES services.
Emerging Use Cases

• ES maximizes customer benefits of PV
• Increased resiliency as a premium service
• DG, DR and ES provide distribution services

These three concepts can be stacked for maximum benefits to customers and utilities
ES maximizes benefits of PV

- ES used with PV as **backup power**
- ES used for **self-consumption** of PV to reduce electric bills (useful when net-metering is not used)
Resiliency as a Premium Service

- Customers connected to a **microgrid** pay premium for increased reliability
- Customers buy or lease **energy storage** for backup power
- Commercial customers buy **generators** for backup power
DG, DR and ES Provide Distribution Services

When dispatched properly, these can have positive impacts on the grid that reduce utility costs

- **Use price signals** to encourage use of devices to provide distribution services
- **Direct utility control** of devices behind-the-meter to provide distribution services
Stacking benefits

• Provide distribution services when the grid is on
• Provide backup power when the grid is out
• Improve benefit-cost ratio for both customer and utility
Green Mountain Power: Powerwall Sales

Customers can buy or lease Powerwalls under 3 pricing schemes

<table>
<thead>
<tr>
<th>Option</th>
<th>Up-front cost</th>
<th>Monthly cost</th>
<th>Monthly Credit</th>
<th>Net Monthly Fee</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option 1: Direct Purchase</td>
<td>$6,501</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Option 2: Direct Purchase with Utility Control</td>
<td>$6,501</td>
<td>$0</td>
<td>$31.76</td>
<td>-$31.76</td>
</tr>
<tr>
<td>Option 3: Rate Rider with Utility Control</td>
<td>$0</td>
<td>$86</td>
<td>$48.50</td>
<td>$37.50</td>
</tr>
</tbody>
</table>

Buffalo Niagara Medical Campus
Distributed System Platform Engagement Tool

• Medical buildings already have backup generators
• Utility will pay customers to generate power during peak times
• Pricing is based on distribution system benefits
BMNC DSP pricing

LMP + D where D = d1 + d2 + d3 + d4 + d5

LMP: Locational Marginal Price

- d1: Avoided Distribution Capacity Infrastructure Costs
- d2: Avoided O&M Costs
- d3: Avoided Distribution Losses
- d4: Avoided Restoration Costs
- d5: Avoided Outage Costs.

D costs calculated using equations from National Grid’s Benefit Cost Analysis Handbook (August 2016)

http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7BF0CC59D0-4E2F-4440-8E14-1DC07566BB94%7D
BMNC DSP Operation

- Calculate LMP + D price
- Send events to BNMC DERs

BMNC DER Owners
- Accept or Reject Events
- Generate Power for Events
- Receive Revenue

Potsdam Resiliency Microgrid

A microgrid consisting of storm-hardened underground wires, generators and critical businesses will be installed

- Hydro Plants
- Combined Heat and Power Plants
- Gas Plants
- Solar Array
- Fire and Police
- Hospital
- National Grid Service Center
- Grocery & Drug Stores
- Water & Wastewater Plants
- College Campuses
- Hotel
- Bank

Customers connected to the microgrid share resiliency costs with surrounding customers who benefit from the operation of emergency services during outages

# Potsdam Resiliency Microgrid Pricing

<table>
<thead>
<tr>
<th>Connection</th>
<th>Tier</th>
<th>Customers</th>
<th>Number of Customers</th>
<th>Cost Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct</td>
<td>1a</td>
<td>Connected Generators</td>
<td>2</td>
<td>6%</td>
</tr>
<tr>
<td></td>
<td>1b</td>
<td>Connected Businesses</td>
<td>10</td>
<td>1.5%</td>
</tr>
<tr>
<td>Indirect</td>
<td>2</td>
<td>Village of Potsdam Border</td>
<td>2,757</td>
<td>14%</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Town of Potsdam Border</td>
<td>3,709</td>
<td>18%</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Nearby towns</td>
<td>4,024</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Surrounding Zip Codes</td>
<td>16,022</td>
<td>50%</td>
</tr>
</tbody>
</table>

Decreasing Cost Per Customer
# Projects Summary

<table>
<thead>
<tr>
<th>Project</th>
<th>State/ Utility</th>
<th>Technology</th>
<th>Services</th>
<th>Pricing</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powerwall Sales</td>
<td>VT/ Green Mountain Power</td>
<td>Energy Storage</td>
<td>Backup Power</td>
<td>Rate Rider + Fixed credit</td>
<td>Utility Control (Optional)</td>
</tr>
<tr>
<td>BMNC DSP Engagement Tool</td>
<td>NY/ National Grid</td>
<td>Distributed Generation</td>
<td>Backup Power</td>
<td>LMP + D</td>
<td>Customer Control with Price Signals</td>
</tr>
<tr>
<td>Potsdam Resiliency Microgrid</td>
<td>NY/National Grid</td>
<td>Microgrid (DG + underground cables)</td>
<td>Backup Power</td>
<td>Tiered Fixed Charge</td>
<td>Utility Control</td>
</tr>
</tbody>
</table>
Next Steps

• Literature review on initiatives and projects outside the US (especially Europe)
• Narrow down use cases to model
Which use cases should we investigate?

- What constraints do we have due to regulations?
- Which services or customer behaviors are we interested in?
  - Peak Shaving
  - Voltage Support
  - Reduced Losses
  - Resiliency & Backup Power
- Which tariff structures are we interested in?
  - Flat vs. Time-of-use vs. Real-time pricing
  - Fixed payment to customers for allowing utility control
  - Utility ownership with rate riders for customer use
Literature Review on Rate Structure

Roghieh Abdollahi, Jeffrey Miller, Garrett Bacon
EXPECTATIONS

What utilities want

• Smooth load profile
• Lower cost price
• Reasonable reliability
• High power quality to have lower possible generation

What customers want

• High power quality to have lower damage in electronic devices and lower payment bill
• Acceptable reliability
• Lower payment bill
• Clear policy and high level of customer services
Effective factors on customer behavior

- Home appliance efficiency including PEVs (Plug in Electric Vehicles)
- Weather (temperature, humidity, ...)
- Weekdays / weekends / holidays
- Renewables
- Storage

The effect of these factors can be summarized as electricity rates, so customer behavior can be directed by electricity rates.
Northern California rates are based on:

- 10 different regions with different kwh of consumption baselines
- Two seasons for billing rates (summer and winter)
- Two different codes
  - Code H: Customers with permanently installed electric heating as the primary heat source
  - Code B: Basic quantities
- Regular or Time of Use (TOU) schedule
- Peak / part peak / off peak for TOU
- Clustering the customers to residential, agricultural, business, and so forth
- **PEVs (plug in electric vehicle)**, according to submitted usage demand (kw) and energy consumption
- **Small Renewables** (less than 1.5 MW), according to the Length of contract and Market-Price-Referent (MPR)
Southern California rates are based on

- 9 different regions with different kwh of consumption baselines
- Two seasons for billing (summer and winter)
- Regular or Time of use (TOU) schedule
- Peak / off peak
- Week days, weekends, and holidays
- Clustering the customers to residential, business, and agricultural

**Electric Vehicle has different rate option**(TOU-D-EV-1), with separate metering

**Renewables**, total capacity should not exceed 1,000 kW and NEM (net energy metering) system is used for measurements
Duke Energy


- Duke energy has different policy for different states.
South Carolina

- Two level of consumption are defined.
- Standard consumption or heating and air conditioner included
- Regular or Time of use (TOU) schedule
- Peak / off peak
  - Different rates for June-September and October-May
  - In peak time customer will be charged for both demand and energy
- Energy STAR certification (ENERGY STAR is a U.S. Environmental Protection Agency voluntary program that helps businesses and individuals save money and protect our climate through superior energy.)
- Clustering the customers to residential, industrial, and general.
North Carolina

- Two level of consumption are defined
- Standard consumption or heating and air conditioner included (different rates for July-October and November-June and level of energy consumption)
- Regular or Time of use (TOU) schedule
- Peak (Monday-Friday) / off peak
  - In peak time customer will be charged for both demand and energy
  - Different rates for June-September and October-May
- Energy STAR certification (ENERGY STAR is a U.S. Environmental Protection Agency voluntary program that helps businesses and individuals save money and protect our climate through superior energy.)
- Clustering the customers to residential, industrial, and general.
Electricity prices in Hawaii are generally higher than on the U.S. mainland due to the cost of imported oil used to power many of the islands' generators.

Because of isolated geographic location, they can not draw power from nearby utility companies in the event of a problem, so they contribute to the higher cost of electricity.
Hawaii Public Utilities Commission (HPUC)

- Three level of consumption are defined, different limit for different Islands
- Regular or Time of use (TOU) schedule
- Peak / off peak and part peak for some Islands
- Clustering the customers to residential, commercial, and general.
- EV metering can be separated
- Customers get paid if they use less than their contracts
Kauai

- **Monthly rates**
- Regular or Time of use (TOU) schedule
- Clustering the customers to residential, large power, commercial and general customers

Average rates for the 5 major islands served by HECO and KIUC

<table>
<thead>
<tr>
<th>Island</th>
<th>Average Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>O'ahu</td>
<td>27.4 cents/kWh</td>
</tr>
<tr>
<td>Molokaii</td>
<td>34.4 cents/kWh</td>
</tr>
<tr>
<td>Lana‘I</td>
<td>34.9 cents/kWh</td>
</tr>
<tr>
<td>Maui</td>
<td>29.3 cents/kWh</td>
</tr>
<tr>
<td>Big Island</td>
<td>32.9 cents/kWh</td>
</tr>
<tr>
<td>Different regions</td>
<td>Northern California</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td></td>
<td>10 regions with daily baselines</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Different baselines</th>
<th>&lt; 100%</th>
<th>&lt; 100%</th>
<th>&lt; 1000 Kwh and &gt; 1000 Kwh</th>
<th>first 350 Kwh</th>
<th>first 200/350 Kwh</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 200%</td>
<td>100%&lt;  &lt; 400%</td>
<td>&gt; 400%</td>
<td>&gt; 350Kw</td>
<td>next 700/850 Kwh</td>
<td></td>
</tr>
<tr>
<td>&gt; 200%</td>
<td>100%&lt;  &lt; 400%</td>
<td>&gt; 400%</td>
<td>&gt; 350Kw</td>
<td>over than 1000/1200Kwh</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Seasonal for billing</th>
<th>summer / winter</th>
<th>summer / winter</th>
<th>summer / winter</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Different codes</th>
<th>Regular / Heating and Air conditioner</th>
<th>Regular / Heating and Air conditioner</th>
<th>Seasonal Regular / Heating and Air conditioner</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Regular or Time of Use (TOU) schedule</th>
<th>for peak time</th>
<th>for peak time and weekdays</th>
<th>for peak time</th>
<th>for peak time</th>
<th>for peak time</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Peak and off peak timing</th>
<th>three definitions</th>
<th>two definitions</th>
<th>two definitions</th>
<th>two definitions</th>
<th>two/three definitions</th>
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</thead>
</table>

<table>
<thead>
<tr>
<th>Clustering the customers</th>
<th>YES</th>
<th>detailed in business</th>
<th>YES</th>
<th>YES</th>
<th>YES</th>
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<table>
<thead>
<tr>
<th>PEV</th>
<th>according to demand and consumption</th>
<th>according to consumption</th>
<th>according to consumption</th>
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</table>

<table>
<thead>
<tr>
<th>Solar Panel</th>
<th>Net metering and contract length</th>
<th>Net metering</th>
<th>Net metering</th>
</tr>
</thead>
</table>

| Storage                               |                                 |              |              |
## Payment bill for three different level of energy consumption in Residential sector

<table>
<thead>
<tr>
<th>Electric Company</th>
<th>Regions</th>
<th>Daily Baselines</th>
<th>Payment Bill ( $ )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>500Kwh</td>
</tr>
<tr>
<td>Duke</td>
<td>South Carolina</td>
<td>1000/30</td>
<td>56.77</td>
</tr>
<tr>
<td></td>
<td>North Carolina</td>
<td>350/30</td>
<td>58.53</td>
</tr>
<tr>
<td></td>
<td>P</td>
<td>13.8</td>
<td>12.3</td>
</tr>
<tr>
<td></td>
<td>Q</td>
<td>7</td>
<td>12.3</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>15.6</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>13.8</td>
<td>11.2</td>
</tr>
<tr>
<td>Pacific Gas and Electric Company (Northern California)</td>
<td>T</td>
<td>7</td>
<td>8.5</td>
</tr>
<tr>
<td></td>
<td>V</td>
<td>8.7</td>
<td>10.6</td>
</tr>
<tr>
<td></td>
<td>W</td>
<td>16.8</td>
<td>10.1</td>
</tr>
<tr>
<td></td>
<td>X</td>
<td>10.1</td>
<td>10.9</td>
</tr>
<tr>
<td></td>
<td>Y</td>
<td>10.6</td>
<td>12.6</td>
</tr>
<tr>
<td></td>
<td>Z</td>
<td>6.2</td>
<td>9</td>
</tr>
<tr>
<td>Southern California Edison</td>
<td>5</td>
<td>13.7</td>
<td>15.2</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>9.4</td>
<td>9.6</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>10.4</td>
<td>9.1</td>
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<td></td>
<td>9</td>
<td>13.8</td>
<td>10.6</td>
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<td></td>
<td>10</td>
<td>16.2</td>
<td>10.8</td>
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<td>13</td>
<td>18.8</td>
<td>10.9</td>
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<td>10.5</td>
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<td>15</td>
<td>39.9</td>
<td>8.2</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>12.1</td>
<td>10.8</td>
</tr>
<tr>
<td>Hawaii</td>
<td>Oahu</td>
<td>(350-850-1200)/30</td>
<td>141.98</td>
</tr>
<tr>
<td></td>
<td>Maui</td>
<td>(350-850-1200)/30</td>
<td>147.05</td>
</tr>
<tr>
<td></td>
<td>Lanai</td>
<td>(250-500-750)/30</td>
<td>176.85</td>
</tr>
<tr>
<td></td>
<td>Molokai</td>
<td>(250-500-750)/30</td>
<td>173.69</td>
</tr>
<tr>
<td></td>
<td>Hawaii</td>
<td>(300-700-1000)/30</td>
<td>165.04</td>
</tr>
<tr>
<td></td>
<td>Kauai</td>
<td>No Baseline</td>
<td>175.97</td>
</tr>
</tbody>
</table>
References

http://www.pge.com/tariffs/index.page
https://www.sce.com/wps/portal/home/customer-service
https://www.duke-energy.com/home/billing/rates
http://puc.hawaii.gov/
http://website.kiuc.coop/content/rates
https://www.hawaiianelectric.com/save-energy-and-money/time-of-use-program
https://www.hawaiianelectric.com/my-account/rates-and-regulations/effective-rate-summary
https://www.hawaiianelectric.com/my-account/rates-and-regulations
Residential PV Modeling with HOMER

Taylor Hill
Why Use HOMER?

• Advances in Distributed Energy Resource (DER) technologies are only beneficial if residential consumers buy and use them at the home
• We want to see the economic value of these technologies on the customer side
• Using HOMER as an economic tool to evaluate what it will take to make PV installation and storage at the home attractive to consumers
  – Analyze the economic incentives that will drive the increase in use of DERs
What is HOMER and its Capabilities?

• Developed by the U.S. National Renewable Energy Laboratory (NREL)
  – Now a tool sold by HOMER Energy
• The HOMER Micropower Optimization Model is an economic tool used to assist in the design of micropower systems and find the least cost combination of components
• HOMER (Hybrid Optimization Model for Multiple Energy Resources) nests three functions:
  – Simulation, Optimization, and Sensitivity analysis
• HOMER allows the modeler to compare many different design options based on their technical and economic merits
Inputs and Outputs

Inputs:
• Location
• Discount Rate
• Average Daily Load (kWh/day)
• Load Profile
  – Residential
  – Commercial
  – Community
  – Industrial
• Grid Information
  – Power Price ($/kWh)
  – Sellback Rate ($/kWh)
  – Pricing Structure Options
• PV Capital Cost ($/kW)
• Battery Options
  – Type
  – Battery Cost ($/kWh)

Outputs:
• Sensitivity Cases
• Within the Optimization Results:
  – System Architecture
  – Cost Summary
    - Total NPC
    - Levelized COE
    - Operating Cost
    - Cash Flow
  – Electrical Results
    - Renewable Production
    - Grid Purchases
    - Load Consumption
    - Excess Electricity
    - Renewable Fraction

*Homer identifies the electrical and economic characteristics per Component
Residential PV + Storage Example

Inputs and Assumptions:

• Scaled Energy Consumption of 48 kWh/day
• Discount Rate of 8%
• 5kW PV at cost of 1950 $/kW
• 14 kWh of Lithium Ion Battery Storage at 100$/kWh
• Utility Energy price starting at $0.1/kWh
  – Sell-back price starting at $0.05/kWh
• All temperature and irradiance data downloaded from NASA surface meteorology and Solar Energy database for Raleigh, NC
Residential PV + Storage Example

- **System Component Sizes**
- **Cost Type and Category Options**
- **Cost Breakdown by Component**
- **Total NPC, Operating Cost, and COE**
- **Graphical Representation of Cost Allocation**

### Cost Summary

**System Architecture:**
- Generic flat plate PV (5,00000 kW)
- Grid (959959 kW)
- Generic 1kWh Lead Acid (14 strings)
- HOMER Cycle Charging
- System Converter (2.04 kW)

**Cost Breakdown:**

<table>
<thead>
<tr>
<th>Component</th>
<th>Capital ($)</th>
<th>Replacement ($)</th>
<th>O&amp;M ($)</th>
<th>Fuel ($)</th>
<th>Salvage ($)</th>
<th>Total ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generic 1kWh Lead Acid</td>
<td>$4,200.00</td>
<td>$2,923.87</td>
<td>$1,789.69</td>
<td>$0.00</td>
<td>($391.44)</td>
<td>$8,522.12</td>
</tr>
<tr>
<td>Generic flat plate PV</td>
<td>$10,500.00</td>
<td>$0.00</td>
<td>$639.17</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$11,139.17</td>
</tr>
<tr>
<td>Grid</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$15,677.51</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$15,677.51</td>
</tr>
<tr>
<td>System Converter</td>
<td>$612.50</td>
<td>$255.57</td>
<td>$0.00</td>
<td>$0.00</td>
<td>($47.57)</td>
<td>$820.50</td>
</tr>
<tr>
<td>System</td>
<td>$15,312.50</td>
<td>$3,179.44</td>
<td>$18,126.37</td>
<td>$0.00</td>
<td>($439.01)</td>
<td>$36,179.30</td>
</tr>
</tbody>
</table>

**Cost Type**
- Net Present
- Annualized

**Categorize**
- By Component
- By Cost Type

**Total NPC:** $36,179.30
**Levelized COE:** $0.1615
**Operating Cost:** $1.632.24
## Residential PV + Storage Example

### Yearly Energy Production by Source

<table>
<thead>
<tr>
<th>Source</th>
<th>Production kWh/yr</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generic flat plate PV</td>
<td>7,011</td>
<td>36.34</td>
</tr>
<tr>
<td>Grid Purchases</td>
<td>12,280</td>
<td>63.66</td>
</tr>
<tr>
<td>Total</td>
<td>19,291</td>
<td>100.00</td>
</tr>
</tbody>
</table>

### Monthly Average Energy Production

![Monthly Average Electric Production](chart.png)

### Load per Year by Electrical Bus Type

<table>
<thead>
<tr>
<th>Type</th>
<th>Quantity kWh/yr</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC Primary Load</td>
<td>17,520</td>
<td>100.00</td>
</tr>
<tr>
<td>DC Primary Load</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>Total</td>
<td>17,520</td>
<td>100.00</td>
</tr>
</tbody>
</table>

### Excess Electricity Production per Year

- Excess Electricity: 1,495.0 kWh/yr (7.7%)
- Unmet Electric Load: 0.0 kWh/yr (0.0%)
- Capacity Shortage: 0.0 kWh/yr (0.0%)

### Max Renewable Penetration and Renewable Fraction

- Renewable Fraction: 29.9%
- Max. Renew. Penetration: 257.9%
### Summary of Results

<table>
<thead>
<tr>
<th></th>
<th>Total NPC</th>
<th>Energy Production (kWh/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage</td>
<td>$8,522.12</td>
<td></td>
</tr>
<tr>
<td>PV</td>
<td>$11,139.17</td>
<td>7,011</td>
</tr>
<tr>
<td>Grid</td>
<td>$15,697.51</td>
<td>12,280</td>
</tr>
<tr>
<td>Converter</td>
<td>$820.50</td>
<td></td>
</tr>
<tr>
<td>System</td>
<td>$36,179.27</td>
<td>19,291</td>
</tr>
</tbody>
</table>

- Levelized COE = $0.1615
- Excess Electricity = 1,495 kWh/yr.
- Renewable Fraction = 30%
Summary and Considerations

• HOMER outputs realistic system models that provide credible system sizes and cost estimations of microgrid systems
  – Given specific and user appropriate inputs

• Can implement different rate structures to analyze different uses of renewables
  – Simple (constant) rate
  – Net Metering (Monthly and Annually)
  – Real Time Rates
  – Demand Rates

• Does Duke currently use a tool to analyze value of PV and energy storage to the customer?

• Are there specific incentive strategies that customers seem to respond to more over others?
Active Distribution Systems: Modelling in OpenDSS

Joshua Smith
Feeder Modeling in OpenDSS

DSS Executive

Circuit

Solution

PDElement
Line
Transformer
Capacitor
Reactor

PCElement
Load
Generator
Vsource
Isource
Storage

Controls
RegControl
CapControl
Relay
Reclose
Fuse

Meters
Monitor
EnergyMeter
Sensor

General
LineCode
LineGeometry
WireData
LoadShape
GrowthShape
Spectrum
TCCcurve
XfmrCode

50
PV Modeling

Block Diagram of the PV System Element Model
Storage Modeling

Block Concept of the Storage Element

Idle | Discharge | Charge

% Eff. Charge/Discharge

kW, kvar

Idling Losses

kWh STORED

Other Key Properties
- % Reserve
- kWhRated
- kWhStored
- %Stored
- kWRated
- etc.
PEV Modeling

• Modeled as a Load:
  – the Loadshape reflects the charging characteristic

• Modeled as a Generator

• Modeled as a Storage Element
  – OpenDSS will limit charge/discharge
Feeder Modeling in OpenDSS

DSS Executive

Circuit

Solution

PDElement
- Line
- Transformer
- Capacitor
- Reactor

PCElement
- Load
- Generator
- Vsource
- Isource
- Storage

Controls
- RegControl
- CapControl
- Relay
- Reclose
- Fuse

Meters
- Monitor
- EnergyMeter
- Sensor

General
- LineCode
- LineGeometry
- WireData
- LoadShape
- GrowthShape
- Spectrum
- TCCcurve
- XfmrCode

54
Modelling in GridLAB-D

Lisha Sun
GridLAB-D

- A power distribution system simulation and analysis tool
- Provide valuable info to utilities that wish to take advantage of the latest energy technologies
- Developed by DOE at Pacific Northwest National Laboratory

<table>
<thead>
<tr>
<th>Feature</th>
<th>CYME (Base)</th>
<th>OpenDSS</th>
<th>GridLAB-D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snap Shot Power flow</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Time Series Analysis</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Distributed Energy Resources</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Physical House/Building Model</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>End-use Model</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Customer Price-responsive Model</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Reliability</td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
Process

Step 1: Feeder Conversion
- Convert Cyme to GridLAB-D Model (GLM)
- Test static power flow run
- Python & PERL

Step 2: Load Addition
- Residential Physical House Model
- Commercial & Industrial
- MATLAB

Step 3: Technology Addition
- Distributed Energy Resources (PV, Energy Storage etc.)
- Controllers & Price signal
- Secondary System
- MATLAB
Customer Modelling Components

Node 671

- XFMR (A)
- XFMR (B)
- XFMR (C)

Triplex Meter

- Meter
- House

- House
- Inverter
- Inverter
- Inverter

- Electric Vehicle
- PV
- Battery
- PV
- Battery
Physical-based Residential House

- House Design Parameters
  - Floor area (sf)
  - Thermal integrity
  - Cooling system type
  - Heating system type
  - Number of stories
  - Number of doors
  - ...

- House Appliance & Controller

- ZIP Load
Market Model

Market Objects

Auction

- Read Price
- Collects, Processes & Clear bids – Market Clearing Price

Controller

- Price Response
- Perform Bid
- 24 hour Market Value moving window (average and standard deviation)

EXAMPLE: HVAC Controller

\[ \Delta T = \frac{\sigma_{\text{actual}}}{Ramp_{\text{high}}} > 0 \]

\[ \Delta T = \frac{\sigma_{\text{actual}}}{Ramp_{\text{low}}} < 0 \]
Price-Based Demand Response

- **Power No Demand Response**
- **Power with Demand Response**
- **Price Signal**

**POWER AT THE TOP OF THE FEEDER**

- **Peak Reduction**
- **Use More Energy**
- **Use Less Energy**

Reduction: 85kW (4%) Peak; 10MWh (1%) Energy
Reliability

“Scheduled” or Random Faults
- Manual
- Random

Perform Faults

Groups Faults
- Meter
- Triplex Meter

Collects Outage info and Metrics

“Scheduled” or Random Faults

Metrics
- SAIFI, MAIFI
- SAIDI, CAIDI
- ASAI

Underlying event types:
- Momentary ≤ 5 minutes; Sustained > 5 minutes

Example Report

<table>
<thead>
<tr>
<th>New Metric Interval started at 2000-01-01 05:00:00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Event #</td>
</tr>
<tr>
<td>Metric Interval Event #</td>
</tr>
<tr>
<td>Starting Date Time</td>
</tr>
<tr>
<td>Ending Date Time</td>
</tr>
<tr>
<td>Object type</td>
</tr>
<tr>
<td>Object Name</td>
</tr>
<tr>
<td>Inducing Object</td>
</tr>
<tr>
<td>Protective Device</td>
</tr>
<tr>
<td>Desired Fault type</td>
</tr>
<tr>
<td>Implemented Fault Type</td>
</tr>
<tr>
<td># of customers affected</td>
</tr>
<tr>
<td>Secondary # of customers affected</td>
</tr>
</tbody>
</table>

SAIFI = 1.23  SAIDI = 0.14  CAIDI = 0.12  ASAI = 1  MAIFI = 11.7
Questions

• Any of the CAPER members using the same methodologies?
• Which features of GridLAB-D should we implement in this project?
• Is it reasonable for us to have access to customer information?
Customer Modeling

David Mulcahy
Previous Project Study Methodology

Converting Circuit to OpenDSS

CYME Database

VBA Tool

OpenDSS Files

MATLAB Control

COM

OpenDSS

Circuit Simulations

Process Data

Process Results

- Trace circuit
- Create figures
- Impact control and results analysis

Process Characteristics

- Validate Results
- Create figures
- Calculate outputs

Impact control and results analysis

Create figures

Calculate outputs

Validate Results

Create figures

Calculate outputs

Circuit Simulations
# Recap: Needs for DER Planning

<table>
<thead>
<tr>
<th>Infrastructure Improvement</th>
<th>Advanced Control</th>
<th>Modeling Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Reconductor</td>
<td>• Volt-VAR</td>
<td>• PV Forecasting</td>
</tr>
<tr>
<td>• Regulator Placement</td>
<td>• Energy Storage</td>
<td>• Full Costs and Benefits</td>
</tr>
<tr>
<td>• Distribution Transformer Sizing</td>
<td>• Smart Inverter</td>
<td>• Operational Impacts</td>
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</table>
Building on Needs from DER Project

<table>
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<th>Infrastructure Improvement</th>
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</table>
Need for Customer Models

• Short-run planning (Customer Operation)
  – Changes in operational behavior
  – Responsiveness to price

• Long-run planning (Customer Investment)
  – Participation in new rate structures or incentives schemes
  – Technology adoption
  – Customer capital investment
Customer Modelling Framework

**Scenarios**
- Technology
  - PV + Energy Storage
  - HEMS (DR)
  - Electric Vehicle
- Ownership
  - Customer Owned
  - Utility Owned

**Tariff Structure**
- Existing Flat & TOU
- Existing Variation
- New rates or Rebates

**Customer Model**

**Physical Model**
- Residential House
- Commercial Building
- Technology

**Behavior Model**
- Price Sensitivity
- Technology Adoption

**Utility Model**

**Distribution Model**
- Demand reduction
- Efficiency improve
- Upgrade deferral

**Time Frame**
- One year
- Five to Ten years
Potential Modeling Tools

**HOMER ENERGy**

Customer equipment sizing based on incentives and controls

**GridLAB-D**

Distribution grid modelling with individual loads and behaviors modeled

**OpenDSS**

Detailed modeling of distribution operation. Calculate effects on utilities’ system.
Questions

• What kind of incentives need to be examined?
  – Purely rates, investment incentives or utility installed equipment programs, etc.?
• What models are helpful to utility engineers?
  – Could CYME with Python be used?
  – Could OpenDSS be used?
• How do utility engineers see customer behavior changing?
• How is the long term adoption of these technologies considered?
Conclusions

Dr. Ramtin Hadidi
Technical Approach

Customer Information
- Customer location
- Type of customer
- Type of loads
- Daily, Weekly, Monthly load profile
- Usage patterns
- Any PV installed?
- PV manufacturer
- PV size
- PV efficiency
- Any Battery Installed?
- Battery manufacturer
- Battery size (energy, power)
- Battery controller
- Battery efficiency
- Battery Application
- Any PEV/PEHV?
- Type of PEV/PEHV
- PEV/PEHV demand
- Type of Charger installed
- Customer rate plan
- Other rates availability

Customer Objects
- Load
  - Residential vs Commercial/
    Power vs Time /
    ...
- PV
  - Size /
    Irradiance/
    Efficiency/
    ...
- BESS
  - Power /
    Energy /
    Efficiency /
    ...
- PEV/PEHV
  - Model/
    Charger Type /
    ...
- Rate Options
  - Rate 1/
    Rate 2/
    ...

Customer Load Modeling
- Power vs Time data with proper resolution

Feeder analysis with customer models included

Planning Strategies and Tools
- Objective
  - Enables customers to install roof PV, BESS, EV without adverse affects to distribution system.
  - How does this boil down to utility decisions?
    - Cables: bigger lines, additional lines, etc.
    - Transformers: best outcome - buy the right size transformer the first time.
    - Help balance the circuit.
Data and Other Requirements

- Customer Information
- Feeder Information
- Software and Licensing
- Factors to consider for planning studies
Thanks !