MERITS OF MICROGRIDS

CASE STUDIES FROM MID-ATLANTIC STATES

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CAMPUS ENERGY 2018 CONFERENCE

BALTIMORE, MARCH 2018
AGENDA

• Why microgrids?
  • Trends in microgrid development
  • Why reciprocating engines and turbines for microgrids?
  • Case studies of Mid-Atlantic States Projects
  • Typical challenges of CHP-RE-DER Challenges
    • Microgrid as a solution – modeling outcome
• Conclusion
## NEED FOR MICROGRIDS- NATURAL/HUMAN DISASTERS

### NATURAL SOURCE OF DISASTER:

<table>
<thead>
<tr>
<th>CAUSE</th>
<th>LOCATION</th>
<th>AFFECTED</th>
<th>DURATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hurricane Sandy (2012)</td>
<td>17 States</td>
<td>8.5 Million People</td>
<td>2-7 Days</td>
</tr>
<tr>
<td>Hurricane Irma (2017)</td>
<td>Puerto Rico/Florida</td>
<td>Islands/Kennedy – OPF</td>
<td>10 Days</td>
</tr>
<tr>
<td>Wildfires (2017)</td>
<td>California</td>
<td>10 Thousand People</td>
<td>Few hours- Days</td>
</tr>
<tr>
<td>Line Flashing &amp; Tree Grounding</td>
<td>West Coast</td>
<td>7.5 Million People</td>
<td>6 Hours</td>
</tr>
</tbody>
</table>

### HUMAN SOURCE OF DISASTER:

<table>
<thead>
<tr>
<th>CAUSE</th>
<th>LOCATION</th>
<th>AFFECTED</th>
<th>DURATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software Bug &amp; Poor Load Shed</td>
<td>Northeast/ Canada (2016)</td>
<td>45 Million People</td>
<td>2-7 Days</td>
</tr>
<tr>
<td>Hot Weather + Technician Error During Maint.</td>
<td>California/ Arizona (2017)</td>
<td>2.7 Million People</td>
<td>12 Hours</td>
</tr>
</tbody>
</table>
TRENDS IN MICROGRID DEVELOPMENT

• Decentralization of energy production, desire for decarbonization and rise of digital assets have changed the dynamics of energy generation.

• High Renewable energy penetration is increasing
  - Low operational expenses
  - Environmentally preferable

• Inherent variability makes them difficult to use as the sole source of power
  - R&D efforts focused on overcoming this, using more inverter-based resources

• The “Anchor” resource is a proven solution
  - Allows a certain penetration ratio of alternative energy (10-30%) with minimal engineering
  - CHP technologies make good anchor resources
  - Variable loads, variable load banks

• High speed Control is required
GROWING NEED FOR FLEXIBILITY
TECHNOLOGY TREND: 1) FOSSIL FUELED DG REPRESENTS NEARLY HALF OF GLOBAL MICROGRID CAPACITY

Planned and Operational Microgrid Power Capacity by Technology, World Markets: 2Q 2018

(Source: Navigant Research)
Note: Other capacity includes DR, geothermal, non-CHP turbines, and others
## TECHNOLOGY TREND: PROPERTIES CRITICAL FOR MICROGRID

### GENERATOR TECHNOLOGIES IN MICROGRID APPLICATIONS

<table>
<thead>
<tr>
<th>Technology</th>
<th>Electrical Output</th>
<th>Emissions</th>
<th>Load Following Ability</th>
<th>Technology Maturity</th>
<th>Desirable Traits for Microgrid Ancghor Resource</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Reciprocating Engines</td>
<td>Synchronous</td>
<td>MEDIUM</td>
<td>MEDIUM</td>
<td>HIGH</td>
<td>1) Dispatchability</td>
</tr>
<tr>
<td>Fuel Cell</td>
<td>Inverter</td>
<td>LOW</td>
<td>LOW TO MEDIUM</td>
<td>MEDIUM TO HIGH</td>
<td>2) Inertia/&quot;stiffness&quot;</td>
</tr>
<tr>
<td>Microturbine</td>
<td>Inverter</td>
<td>LOW</td>
<td>MEDIUM TO HIGH</td>
<td>MEDIUM TO HIGH</td>
<td>3) Quick response</td>
</tr>
<tr>
<td>Gas Turbine</td>
<td>Synchronous</td>
<td>LOW</td>
<td>MEDIUM TO HIGH</td>
<td>HIGH</td>
<td>4) Medium To High Technology Maturity</td>
</tr>
<tr>
<td>Diesel Reciprocating Engine</td>
<td>Synchronous</td>
<td>HIGH</td>
<td>HIGH</td>
<td>HIGH</td>
<td>5) Medium to Low Emissions</td>
</tr>
<tr>
<td>Battery Energy Storage</td>
<td>Inverter</td>
<td>ZERO</td>
<td>HIGH</td>
<td>MEDIUM</td>
<td></td>
</tr>
<tr>
<td>Solar PV</td>
<td>Inverter</td>
<td>ZERO</td>
<td>LOW</td>
<td>HIGH</td>
<td></td>
</tr>
<tr>
<td>Wind Turbine</td>
<td>Inverter</td>
<td>ZERO</td>
<td>LOW</td>
<td>HIGH</td>
<td></td>
</tr>
</tbody>
</table>
TECHNOLOGY TREND: 2) SOLAR PV FALLING IN PRICE
INCREASINGLY COMPETITIVE WITH FOSSIL-FUELED DG

(Sources: Navigant Research, Energy Information Administration, Lazard)

Genset LCOE based on same-year installation and 20-year life and 2.5% cost of fuel escalation. Diesel based on average US retail Ultra Low Sulfur Diesel prices; natural gas based on average price paid by US industrial users.
TECHNOLOGY TREND: 3) DERS CATCHING UP WITH GENSETS FAST

Annual Installed DER Capacity, Selected Technologies, World Markets: 2017-2026

(Source: Navigant ReSearch)
FOSSIL FUELED “PRIME MOVERS”: A CLOSER LOOK

<table>
<thead>
<tr>
<th></th>
<th>Diesel Reciprocating Engine</th>
<th>Natural Gas Reciprocating Engine</th>
<th>Gas Turbine</th>
<th>Fuel Cell</th>
<th>Microturbine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Share of Total Global Microgrid Capacity, 2Q17</td>
<td>25%</td>
<td>3%</td>
<td>17%</td>
<td>1%</td>
<td>&lt;1%</td>
</tr>
<tr>
<td>Typical Installed Cost/kW</td>
<td>$500-$900</td>
<td>$700-$1,200</td>
<td>$800-$1,400</td>
<td>$4,000-$9,000</td>
<td>$2,500-$4,000</td>
</tr>
<tr>
<td>Load Following Ability</td>
<td>Best</td>
<td>OK Medium</td>
<td>OK</td>
<td>Poor</td>
<td>OK</td>
</tr>
<tr>
<td>Emissions</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
<td>V. Low</td>
<td>Low</td>
</tr>
<tr>
<td>Outlook</td>
<td>(↔) Low cost, versatile, trusted, but emissions &amp; fuel costs a major drag</td>
<td>(↑↑) Cheap, modular, efficient; growing availability of NG is key</td>
<td>(↑) Well suited for larger applications with access to high-pressure NG</td>
<td>(↑) High cost + inflexibility curb demand; remains longer-term threat</td>
<td>(↑) High cost a challenge vs alternatives; CHP applications attractive</td>
</tr>
</tbody>
</table>
WHY NATURAL GAS RECIPROCATING ENGINE?

LAST DEFENSE TO KEEP THE POWER FLOWING 24/7

Operation

- **Electrical efficiencies up to 45%**
- High sound power levels
- Does not take on load as fast as diesel generator
- **High availability (98%)**
- NG lines underground
- Are modular and easy to site
- Fuel Flexibility
- operate at high altitudes and in ambient temperatures
- Approx. Cost $2,800/kW as part of a CHP

Three- 2.5 MW Caterpillar Gen-sets
NATURAL GAS TURBINES

• 24/7 Operation
• Power output reduction as inlet air temperature increases
• 24-42% electrical efficiency depending on size
• Lower O&M costs relative to recip. engines.
• Approx. Cost $3,000/kW as part of CHP system
NATURAL GAS MICROTURBINES

• Does not require a building enclosure
• Low sound power levels and emissions
• Low O&M costs
• Low electrical efficiency (22-33%)
• Significant power output loss at ambient temp. above 73F
• Approx. Cost $3,500/kW as part of CHP

200 kW Microturbines-Courtesy of Capstone
STEAM TURBINES

• 40+% Efficient
• Requires a steam source and steam demand
• Low sound power
• Low O&M cost
• May be combined with gas turbine system
• Low installed cost, approx. $1,100/kW
Case Studies of Microgrid Projects in Mid-Atlantic States
MICROGRIDS AND THEIR VALUE PROPOSITIONS FOR DIFFERENT END-USE SECTORS
1. UPPER CHESAPEAKE MEDICAL CENTER

Goal: To have reliability and resilient power
• 2 MW CHP Caterpillar natural gas engine
• Diesel gen-set + Absorption Chiller
• Financed by the end user through PPA financing by Clark Financial Services Group
CHP MICROGRID SYSTEM OPERATION

- 100 KW Minimum import requirement
- Variable base load
- Resiliency for HVAC and other building loads
- Additional backup to the code-required diesel during extended utility outages
Goal: To have reliability, flexibility, lower cost operation

- Take advantage of new opportunities resulting from campus electrical consolidation project
- Increase power reliability to support entire campus
- Optimize existing CHP by increasing thermal load
- Further reduce carbon footprint
- Further reduce operating Costs
- Increase Chilled Water Capacity
LOAD ANALYSIS – THE IMPORTANCE OF INTERVAL DATA

Averages Ignore Demand Valleys
LOAD ANALYSIS – CONSOLIDATED ELECTRICAL LOAD PROFILE

Baseline Demand

Electric Demand (kW)
LOAD ANALYSIS – NATURAL GAS & HOT WATER LOAD PROFILES

Graph showing natural gas and hot water demand profiles over time.
LOAD ANALYSIS – CHILLED WATER LOAD PROFILES

Chilled Water Demand (Tons)

500-600 Ton Baseline Demand
**MICROGRID-CHP AND OTHER COMPONENTS**

**CHP-6000**
- **2500 KW**

**CHP-6001**
- **2500 KW**

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**Electrical**

- **Scope**
  - Relocate existing CHP-6000 tie-in
  - Connect new CHP-6001
  - Modify PMCS to stage multiple CHP units.

**Hot Water Systems**

- **Scope**
  - Extend hot water piping to Area 3 and Area 4.
  - Add controls to regulate flow to multiple hydronic systems

**Steam Systems**

**Chilled Water Plant**

- **Scope**
  - Extend hot water and steam piping to chiller plant
  - Chilled water connection
  - New cooling tower and chiller
CHALLENGES OF RENEWABLE PENETRATION - A MICRORID SOLUTION

- MICROGRID SOLUTION:
- CHP + STORAGE + SOLAR:
  - CREATING A FIRM, DISAPATCHABLE ASSET TO ADDRESS UTILITY NEEDS AS WELL AS CUSTOMER NEEDS
  - MICROGRID ALLOWS CHP TO BE OPTIMIZED – INCREMENTALLY ADDING ASSETS, SOLAR & STORAGE TO ADDRESS FACILITY PEAK AS WELL AS ADDING FLEXIBILITY TO PARTICIPATE IN GRID SERVICES
MICROGRID – MODELING METHODOLOGY

• Modeled a large commercial 2000 kW facility such as a large university campus with grid only as the baseline

• Modeled same with 1) CHP only 2) CHP with battery storage, 3) CHP with solar 4) CHP with battery and solar

• Conclusion:

• For an university campus, CHP microgrid with PV and battery provides additional benefits at a slightly expensive system cost. The resiliency and peak-shaving benefits will outweigh the cost difference.
Battery discharges highest during peak-loads in summer at a much lower cost vs demand charges. Due to this the yearly reserve for the site is reduced and hence the overall yearly electricity bills by 20-25%.
Conclusion: Net Present Cost for 15 year for the system is $29.3 million from capital costs of CHP and battery. Highest expenses for this comes from fuel for CHP and O&M as in the break-down of expenses in the table.
## CONCLUSION: BENEFIT OF MICROGRID VALUE STACKS

<table>
<thead>
<tr>
<th>System</th>
<th>Type</th>
<th>Net Present cost</th>
<th>Rebates-utility</th>
<th>Grant-State</th>
<th>Federal Tax Credits</th>
<th>Net after financial assistance, $</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% Grid</td>
<td>Layer 1</td>
<td>20,328,240</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>20,328,240</td>
<td>Baseline</td>
</tr>
<tr>
<td>2640 CHP + 10 kW grid</td>
<td>Layer 2</td>
<td>22,038,060</td>
<td>2,500,000</td>
<td>499,999</td>
<td>475,200</td>
<td>19,038,061</td>
<td>Good Option 1 Vs 100% grid Baseline</td>
</tr>
<tr>
<td>2640 kW CHP+806 kW PV+6631 kWh battery</td>
<td>Layer 3</td>
<td>26,207,160</td>
<td>2,500,000</td>
<td>499,999</td>
<td>1,824,888</td>
<td>21,382,273</td>
<td>Good Option 2 Vs 100% grid Baseline</td>
</tr>
<tr>
<td>2640 kW CHP + 17555 kWh battery, no grid, no solar</td>
<td>Layer 4</td>
<td>29,372,030</td>
<td>2,500,000</td>
<td>499,999</td>
<td>2,055,150</td>
<td>24,316,881</td>
<td>Good Option 3 Vs 100% grid Baseline</td>
</tr>
</tbody>
</table>

Nandini Mouli, eSai LLC, 12,11,17

Large Commercial, Comparison of Financials with and without Renewable Sources
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