Metrics for Resilience in Theory and in Practice – A Workshop

Joseph H. Eto
Lawrence Berkeley National Laboratory
70th Annual NECPUC Symposium,
Cape Neddick, ME
May 22, 2018
Overview of this workshop

► Part 1 (25 min) Setting the stage – Eto
  ■ Distinguishing between reliability vs. resilience
  ■ DOE’s Grid Modernization Initiative’s grid resilience metrics
  ■ Sandia National Labs’ grid resilience planning case study for the City of New Orleans
  ■ A structured approach for resilience planning

► Part 2 (50 min) An interactive application
  ■ Avangrid’s Coastal Substation Flood Mitigation Study by David Bradt, Avangrid (CT) (20 min)
  ■ Directed Q/A – led/moderated by Joe Eto with audience participation (30 min)
# Reliability vs. Resilience

<table>
<thead>
<tr>
<th></th>
<th>Reliability</th>
<th>Resilience</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Common features/characteristics</strong></td>
<td>Routine, not unexpected, normally localized, shorter duration interruptions of electric service</td>
<td>Infrequent, often unexpected, widespread/long duration power interruptions, generally with significant corollary impacts</td>
</tr>
<tr>
<td></td>
<td>Larger events will make it into the local headlines</td>
<td>Always front page news, nationally</td>
</tr>
<tr>
<td><strong>Metrics</strong></td>
<td>Well-established, annualized (SAIDI, SAIFI, MAIFI), with provisions for “major events”</td>
<td>Not standardized, event-based (number of customers affected; hours without electric service)</td>
</tr>
<tr>
<td></td>
<td>Not focused on non-electricity impacts</td>
<td>Routinely include non-electricity impacts (e.g., costs to firms; health and safety impacts)</td>
</tr>
<tr>
<td><strong>Actions to improve</strong></td>
<td>1. Plan and prepare; 2. Manage and endure event(s); 3. Recover and restore; and 4. Assess, learn, and update plan.</td>
<td>No qualitative difference</td>
</tr>
<tr>
<td></td>
<td></td>
<td>But generally larger in scope/cost (see below)</td>
</tr>
</tbody>
</table>
### Reliability vs. Resilience

<table>
<thead>
<tr>
<th>Entities involved in decision making</th>
<th>Reliability</th>
<th>Resilience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric utility and its regulator/oversight board, primarily</td>
<td>Electric utility and regulator But also and routinely in conjunction with parties that have responsibilities for other critical infrastructures, including local/regional/state/federal agencies/authorities, and communities/elected officials</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Factors affecting decision making</th>
<th>Reliability</th>
<th>Resilience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actuarial records on frequency of exposure – widely understood risks: insurable</td>
<td>No actuarial basis to establish likelihood of occurrence – widely varying perceptions of risk/exposure: un-insurable</td>
<td></td>
</tr>
<tr>
<td>Well-understood/tested practices/approaches</td>
<td>Limited opportunities to “test” strategies; emphasis on design standards</td>
<td></td>
</tr>
<tr>
<td>Understood to be an expected cost of doing business</td>
<td>Large dollar amounts/extraordinary expenditures may require special approval/vote</td>
<td></td>
</tr>
<tr>
<td>Political judgements essential</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# Landscape of existing and proposed metrics

## Resilience

<table>
<thead>
<tr>
<th>Existing (metrics)</th>
<th>Existing (data needed)</th>
<th>Proposed Metrics</th>
<th>Proposed (data needed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of recovery</td>
<td></td>
<td>Cumulative customer-hours of outages</td>
<td>customer interruption duration (hours)</td>
</tr>
<tr>
<td>Utility revenue lost</td>
<td>outage cost for utility ($)</td>
<td>Cumulative customer energy demand not served</td>
<td>total kVA of load interrupted</td>
</tr>
<tr>
<td>Cost of grid damage</td>
<td>total cost of equipment repair</td>
<td>Avg (or %) customers experiencing an outage during a specified time period</td>
<td>total kVA of load served</td>
</tr>
<tr>
<td>Cost per outage</td>
<td></td>
<td>Cumulative critical customer-hours of outages</td>
<td>critical customer interruption duration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Critical customer energy demand not served</td>
<td>total kVA of load interrupted for critical customers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Avg (or %) of critical loads that experience an outage</td>
<td>total kVA of load severed to critical customers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Time to recovery</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cost of recovery</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loss of utility revenue</td>
<td>outage cost for utility ($)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cost of grid damages (e.g., repair or replace lines, transformers)</td>
<td>total cost of equipment repair</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Avoided outage cost</td>
<td>total kVA of interrupted load avoided $ / kVA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Critical services without power</td>
<td>number of critical services without power</td>
</tr>
<tr>
<td></td>
<td></td>
<td>total number of critical services</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Critical services without power after backup fails</td>
<td>total number of critical services with backup power</td>
</tr>
<tr>
<td></td>
<td></td>
<td>duration of backup power for critical services</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loss of assets and perishables</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Business interruption costs</td>
<td>avg business losses per day (other than utility)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Impact on GMP or GRP</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Key production facilities w/o power</td>
<td>total number of key production facilities w/o power (how is this different from total kVA interrupted for critical customers?)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Key military facilities w/o power</td>
<td>total number of military facilities w/o power (same comment as above)</td>
</tr>
</tbody>
</table>
A structured approach to resilience planning

► What resilience threat(s) is the focus?
► What aspect(s) of the threat(s) is of concern?
  ■ Can we measure the extent to which these concerns are or will be addressed? How will we know if we have made things better or if they are getting worse (in the absence of an actual threat)
► What is our design standard for addressing these concerns?
► What are the pro’s and con’s of available alternatives for meeting these standards?
  ■ What is the lowest cost option?
  ■ What, if any, additional benefits might they provide? What are these worth?
  ■ Are there options for recourse?
Grid Analysis and Design for Energy and Infrastructure Resilience in New Orleans, LA

Robert Jeffers, Michael Hightower, Michael Baca, Nancy Brodsky, Amanda Wachtel, Sarah Walsh, Bill Fogleman
New Orleans is using technical assistance from Sandia and Los Alamos to determine grid investments that will improve their resilience to storms.
Consequence-focused Scenarios

A high category 2 or low category 3 may lead to worst reasonable consequence in NOLA

- If it stalls and drops >20” of rain quickly
- The city does not call for a mandatory evacuation
- Address potential worst case dewatering pump performance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Track 1: Katrina 2005</th>
<th>Track 2: Unnamed Storm Sept. 1947</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storm Category</td>
<td>High Cat 2; surge &lt;20 ft</td>
<td>Mid-range Cat 3; surge ?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low – mid range Cat 4; surge likely &gt; 24 ft</td>
</tr>
<tr>
<td>Rainfall</td>
<td>20 inches over ~ 24 hours</td>
<td></td>
</tr>
<tr>
<td>Drainage Pumps</td>
<td>Performing at 50% capacity</td>
<td></td>
</tr>
</tbody>
</table>
Population movement to dry areas

Baseline Population

Inundated Population (>2 Feet) Movement to Potential Shelters

Population Density/Square Mile

0 - 370
370 - 1,482
1,482 - 2,660
2,660 - 4,341
4,341 - 6,213
6,213 - 8,926
8,926 - 13,157
13,157 - 17,831
17,831 - 38,254
38,254 - 58,882

Baseline Population 2014 data from the 2010-2014 American Community Survey, Table S0101, Orleans Parish
Decentralized Infrastructure and Inundation

Note: purpose of inundation analysis is to guide energy system improvements, not to be used for facility elevation studies.
Microgrid Screening

Red = No critical infrastructure in area
Yellow = Critical infrastructure in area, but less than required
Green = Critical infrastructure, meets user-defined requirement

Area size of 1000 ft x 1000 ft
Minimum of 4 buildings per microgrid
Southwest Connecticut Coastal Flood
Risk Assessment & Mitigation

Presentation to:
NECPUC Annual Symposium

David Bradt
Director – Transmission Planning
Objective:
Share Avangrid’s recent experience with increasing flood risk threats along the SWCT coastline along with actions to date.
Background

1970 thru 2010

- No record of disruptive coastal S/S flood events
- Design Levels
  100yr (pre-90’s)
  100yr +1 (post 90’s)

Storm Irene (August 2011)

- Singer S/S
- Pequonnock S/S

Storm Sandy (October 2012)

- Congress S/S
- Pequonnock S/S

2013

- FEMA revises Flood Maps 2-4ft (July 2013)
- Compelled to take Action
- Short Term Measures in place (August 2013)
- Initiate Long Term Assessment
- Stakeholder process
Risk Assessment

- A 50yr substation designed to the 100year flood level has a 40% chance of flooding over its useful life.
- 5 stations at risk from single flood event could destroy 5 BES stations

Establish Criteria

Industry, Regional, Sea Level Rise

Legacy Stations
100year flood level

New or Modified
Higher of:
a) “100-year flood level + 2 feet” or,
b) “500 year flood level” → plus 1ft coastal SLR consideration

Alternative Development

- Raise equipment
- Flood wall system
- Raise/Rebuild
- Relocate inland
- Address Asset Condition Needs

Reference: Designing for Flood Levels Above the BFE After Hurricane Sandy (FEMA HSFE60-13-0002, 0003, April 2013)
# Southwest Connecticut Alternatives & Recommendations (Examples)

<table>
<thead>
<tr>
<th>Mitigation Strategies</th>
<th>Congress St</th>
<th>Pequonnock</th>
<th>Singer</th>
<th>Grand Ave/Mill River</th>
<th>East Shore</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Solution Alternative Cost ($M)</td>
<td>Solution Alternative Cost ($M)</td>
<td>Solution Alternative Cost ($M)</td>
<td>Solution Alternative Cost ($M)</td>
<td>Solution Alternative Cost ($M)</td>
</tr>
<tr>
<td>1 Raise Impacted Equipment</td>
<td>Infeasible (Control Building Impacted)</td>
<td>Infeasible</td>
<td>Infeasible</td>
<td>Infeasible</td>
<td>$0.33</td>
</tr>
<tr>
<td>2 Perimeter Flood Wall System</td>
<td>$16.50</td>
<td>Not pursued</td>
<td>$12.90</td>
<td>$17.50</td>
<td>$21.00</td>
</tr>
<tr>
<td>3 Raise and Rebuild “Adjacent”</td>
<td>$88.30</td>
<td>$171.30</td>
<td>$194.60</td>
<td>$88.30</td>
<td>Not pursued</td>
</tr>
<tr>
<td>4 Raise and Rebuild “In-Place”</td>
<td>Not pursued (Cost exceeds Rebuild “Adjacent”)</td>
<td>$269.60</td>
<td>Not pursued</td>
<td>Infeasible</td>
<td>Not pursued</td>
</tr>
<tr>
<td>5 Relocate Inland</td>
<td>$233.30</td>
<td>$246.70</td>
<td>Infeasible</td>
<td>$207.40</td>
<td>Not pursued</td>
</tr>
<tr>
<td>6 Address Asset Condition Needs (non-flood related)</td>
<td>None Identified</td>
<td>Included in above costs</td>
<td>None Identified</td>
<td>Included in above costs</td>
<td>None Identified</td>
</tr>
</tbody>
</table>

**Recommended Mitigation Strategy - Highlighted**

|                              | $16.5       | $171.3      | $12.9       | $17.5       | $0.3         |

**Total Estimated Solution Costs:** $218.5
Execution of Plans (in progress)

Continued Evidence of Coastal Flood Pattern Changes

2022 ISD

Mitigation Plans now Underway

- Raising Equipment
- Flood wall systems
- S/S Rebuild

Congress S/S
(10/28/2015)

Pequonnock S/S
(1/23/2016)

Congress S/S
(3/2/2018)

Pequonnock S/S
(3/4/2018)
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