Towards Metrics for Resilience Characterization and Challenges in Valuing Distribution System Resilience Improvements

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GMLC 1.1 METRICS ANALYSIS
GMLC1.5.7: LAB VALUATION ANALYSIS TEAM

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Resilience Workshop

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Overview of Presentation

► Landscape of metrics and processes specific to resilience characterization
► Delineation between **reliability** and **resilience**
► 2 approaches toward Resilience Characterization
  ■ Attribute-based
  ■ Performance-based
► Example of R&D to improve resilience of grid infrastructure and how to value it.
When reliability ↑ then (usually - NOT always) resilience ↑

When flexibility ↑ then resilience ↑
# Landscape of Existing and Proposed Metrics – Example: Reliability (GMLC 1.1)

## Distribution Reliability

<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>SAIFI</td>
<td>Total customers served</td>
<td></td>
<td>Interruption Cost</td>
</tr>
<tr>
<td>SAIDI</td>
<td></td>
<td></td>
<td>Customers interrupted (by type of customer)</td>
</tr>
<tr>
<td>CAIDI</td>
<td>Customer interruption duration</td>
<td></td>
<td>Characteristics of interruptions by customer type (e.g., duration, start time)</td>
</tr>
<tr>
<td>CAIFI</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CTCAIDI</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASAI</td>
<td>Customer hours service availability</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAIFI</td>
<td>Total customer momentary interruptions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CEMI</td>
<td>Total customers experiencing more than n sustained outages</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CEMSMI</td>
<td>Total customers experiencing more than n momentary interruptions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CI</td>
<td>Customers interrupted</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CMI</td>
<td>Customer minutes interrupted</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASIFI</td>
<td>Total connected kVA of load interrupted</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASIDI</td>
<td>Total connected kVA served</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CELID</td>
<td>total number of customers that have experienced more than eight interruptions in a single reporting year</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SARI</td>
<td>Circuit outage number and duration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COR</td>
<td>number of correct operations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COR</td>
<td>total number of operations commanded</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DELI</td>
<td>total distribution equipment experiencing long outages</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DEMI</td>
<td>length of interruption (by equipment type)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACOD</td>
<td>Transmission circuit outage and duration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACSCI</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TACS</td>
<td>total amount of equipment that have more than N # of interruptions in a single year</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FOHMY</td>
<td>Outages per hundred miles per year</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# Landscape of Existing and Proposed Metrics – Example: Resilience (GMLC 1.1)

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

### Emerging

**Direct impacts**
- Customer services

**Indirect impacts**
- Community services

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**Emerging**

**Community services**

**Direct impacts**
- Customer services

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**Emerging**

**Direct impacts**
- Customer services

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**Emerging**

**Direct impacts**
- Customer services
Differentiation between Reliability and Resilience events

Reliability
Ability to provide electric services under \textit{normal} operating conditions (\textit{blue sky})

Resilience
Ability to operate in full or reduced form during \textit{abnormal} operating conditions (\textit{black sky})

valuation differences between reliability and resilience improvements

\textbf{Blue sky} threat conditions
- Outages: usually $\leq 24$ hours
- Statistics of failure and outage duration known (SAIDI, SAIFI)
- Consequence:
  - outage cost for all customers

\textbf{Black sky} threat conditions
- Outages: usually $> 24$ hours
- Statistics of failure and outage duration unknown (SAIDI, SAIFI)
- Consequence:
  - outage cost for all customers
  - Loss of community services
Differentiation between Resilience and Reliability

**Metrics: Reliability**

<table>
<thead>
<tr>
<th></th>
<th>Customer’s perspective</th>
<th>Utility’s perspective</th>
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<tr>
<td>SAIDI, SAIFI</td>
<td>Outage cost by customer</td>
<td>Lost revenue</td>
</tr>
<tr>
<td>CAIDI, CAIFI</td>
<td>Restoration cost</td>
<td></td>
</tr>
<tr>
<td>...</td>
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</table>

LBNL’s ICE calculator
Valid for reliability events
Up to 24 hours

**Metrics: Resilience**

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<th>Utility’s perspective</th>
<th>Community’s perspective</th>
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<tr>
<td>SAIDI, SAIFI</td>
<td>Outage cost by customer</td>
<td>Lost revenue</td>
<td>Disruption of critical community services</td>
</tr>
<tr>
<td>CAIDI, CAIFI</td>
<td>Restoration cost</td>
<td></td>
<td>Impacts of Economic disruptions on Gross Regional Product</td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
<td>Large reconstruction cost</td>
</tr>
</tbody>
</table>

- Direct impacts/consequence: Interruption cost. No data exist for multi-day interruptions. Notionally, damage costs increase more than linearly over time
- Indirect/induced impacts:
  - community disruptions (impact safety, health and wellbeing)
  - Economic disruption costs: percolates through local/regional economy
Methodology and Data Requirements for Determining Value of Resilience vs. Reliability

**Resilience value**

- **Difference**
  - Black-versus blue sky threats
  - For long-term outages we estimate LOST COMMUNITY SERVICE

**Reliability value**

- **Difference**
  - Black-versus blue sky threats
  - For long-term outages we estimate LOST COMMUNITY SERVICE

**Delta**

- Outage duration by customers

**Valuation**

- Value of lost load
- Value of lost community service

**Benefit/cost estimate**

**Cost of equipment**
Two Approaches toward Developing Resilience Metrics

➤ **Approach 1: Consequence-based**
- Addresses the consequences of one or multiple threats to an asset or infrastructure
- **Applications**: Assess consequences (direct and indirect) of threats. And used for assessing mitigation strategies to explore change in consequences. This approach is usually associated with projections and modeling (leading indicators)
- **Purpose**: Prioritizing investments for infrastructure hardening and mitigation strategies.

➤ **Approach 2: Attribute-based**
- Addresses the survivability posture of an asset or infrastructure to a threat or the ability to recover from a threat; predicated on sets of attributes that describe level of
  - Preparedness
  - Ability to resist and absorb
  - Ability to respond, adapt, and recover
- **Applications**: Requires a detailed survey instrument to collect resilience attribute characteristics and an elicitation process to define their contribution to the overall resilience
- **Purpose**:
  - Used for monitoring progress on the resilience posture
  - Enables comparability to peers and any other cohorts

➤ **Synergies between Approach 1 + 2:**
- Attribute-based approach can be used for screening to identify grid components that could be modified to enhance resilience
- Consequence-based approach can be used to analyze investment alternatives
- Will be applied to a New Orleans case study
Resilient Distribution Systems
Demonstration with City of Cordova, AK

► Project Name
  ■ Resilient Alaskan Distribution System Improvements using Automation, Network Analysis, Controls, and Energy Storage (RADIANCE) Field Validation

► Technology
  ■ Advanced metering/improvements to situational awareness
  ■ Upgrades to SCADA systems and/or advanced distribution controls
  ■ High-resolution fuel metering
  ■ High-resolution of water metering/penstocks
  ■ Integration hardware/software for grid-scale battery
  ■ Pumped hydro storage and solar assessments/modeling
  ■ Sectionalized hardware and controls for fault isolation
  ■ Information technology (IT) upgrades to enhance cybersecurity

► Field Validation
  ■ Multiple tests of device operations

► Use cases to be tested
  ■ Various configurations of microgrid operations under black sky conditions

► Values to be demonstrated
  ■ Primarily avoided economic impacts under black sky conditions

► Challenges
  ■ Projecting frequency of black sky events over the lifecycle of technologies
  ■ Field validation, inducing faults and demonstrating resilient behavior
How do you demonstrate Resilience?

Most technology solutions include redundant systems (hardening) and additional flexibility assets to reconfigure electric circuits.

Most Field-tests will focus primarily on low-intrusive device-level functionality. Then infer how system might behave under black-sky conditions using complex simulations.

Biggest challenge in valuation of resilience investments is the estimation of severity and frequency of black sky conditions. Assumptions are key driver for economic justification.
Exploring Investment Options on Consequences to Threats

Baseline

Weather Conditions (e.g., trajectory, wind speeds, etc.)

Effects of Weather (e.g., physical damage)

Model of Grid Ops

Histogram of Grid Consequences (e.g., Shed Load)

With Mitigation

Weather Conditions (e.g., trajectory, wind speeds, etc.)

Effects of Weather (e.g., physical damage)

Effects of Investment Options

Model of Grid Ops

Histogram of Grid Consequences (e.g., Shed Load)

Change in histogram represents resilience improvement
Principles of ATTRIBUTE-BASED Approach

Resilience index is based on 4 sub-indices

Level 1
- Preparedness
- Mitigation Measures
- Response Capabilities
- Recovery Mechanisms

Level 2
- Awareness
- Planning
- Mitigating Construction
- Utility Mitigation
- Onsite Capabilities
- Offsite Capabilities
- Resources Mitigation Measures
- IMCC Characteristics
- Restoration Agreements
- Recovery Time

IMCC: incident and management control center