Overview of Resilience Planning Framework

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Sandia’s History

- July 1945: Los Alamos creates Z Division
- Nonnuclear component engineering
- November 1, 1949: Sandia Laboratory established

Exceptional service in the national interest
Energy crisis of the 1970s spawned the beginning of significant energy work.

- **1970**: Strategic Petroleum Reserve, Vertical-axis Wind Turbine, Solar Tower opens, Combustion Research Facility (CRF) opens to researchers, NRC cask certification studies & core melt studies.


- **2010**: MELCOR code released, SunCatcher™ & Stirling Energy Systems, Climate study uncertainties to economies, Fukushima Recovery.


- **2013**: Solar Glare Analysis Tool (SGHAT), New diesel low-temp combustion model, Mesa del Sol microgrid demo, PV Regional Test Centers (RTCs).
Resilience Analysis Approach is Threat-Based, Rigorous, and Quantifiable

- Probability of Consequences \[ P(X) \]
- Consequences \[ C \]
- Reduced Expected Financial Consequence \[ E'(C) \]
- Reduced Risk \[ E(C) \]
- Resilience of System After Improvements
- Baseline System Resilience
- Improvements must cost significantly less than \( E - E' \)

Define Resilience Goals
Define System & Resilience Metrics
Characterize Threats
Determine Level of Disruption
Define & Apply System Models
Evaluate Resilience Improvements
Calculate Consequence
Energy Resilience Enables Community and Installation Resilience

The grid is the keystone infrastructure – central to the web of interconnected systems that support life as we know it.
Resilience and Reliability

Includes *low probability, high consequence* events.

Not widely adopted. Still working on *methods, metrics, and tools*.

Focuses on system performance with respect to *commonly expected events* (component failure, etc.).

* Widely adopted* for infrastructure investment decision-making.
Defining Resilience

Ability to Prepare for, Withstand, and Recover from disruptions caused by major Accidents, Attacks, or Natural Disasters.

1. Resilience is contextual – defined in terms of threats or hazards
   • A system resilient to hurricanes may not be resilient to earthquakes
2. Includes hazards with low probability but potential for high consequence
   • Naturally fits within a risk-based planning approach…
   • …but difficult to capture this type of risk with high confidence
Resilience Planning Process

1. Identify location and key characteristics

2. Determine Design Basis Threats (DBTs)

3. Assess baseline resilience given emergency operations plan

4. Determine and analyze base case conceptual design

5. Develop and evaluate alternative conceptual designs

6. Compare metrics for baseline, base case, and alternative conceptual designs
Step 1: Location and Key Characteristics

• Select location to be analyzed for resilience
  • Currently focusing on a framework that can be used for mid-size areas with simplified owner and funding situations such as:

- Military Installations
- Hospitals
- Campuses
- Public Housing

• Understand key characteristics of the given location
  • One-source funding vs. multi-source funding
  • Single-owner vs. multi-owner
Step 2: Determine Design Basis Threats

- The resilience planning framework will include a detailed listing of various threat types and where to obtain more data on a specific threat.
- Threats may be *man-made*, accidents, or *natural disasters* and should include probability distributions.
- Threat profiles should be at community level and then applied to buildings, distribution system, etc.
- For a given location, users must down-select from the master list of threats to a list that is specific to their area.
Threat Characterization

- Need hazard magnitude (PDF or fixed probability) for each threat and location
- Probabilities may change over the planning horizon
- Want to be forward-looking so may need to use data with simulation model and project out to future years

**Sources of Threat Data**
- FEMA: inundation, wind, earthquakes, wildfires
- USGS: landslides
- NOAA: extreme heat, extreme cold, drought
- Sensor/record data

**Threat distributions are needed for each threat type/combo and can be obtained from various sources**
Step 3: Determine Appropriate Resilience Metrics

- Determine whether location is best served by operational resilience metrics or community resilience metrics
  - Operational resilience metrics: mission/function based
    - Ensure entity’s ability to carry out critical missions/functions during and after an extreme event
  - Community resilience metrics: service based
    - Ensure members of the community have access to critical services during and after an extreme event

<table>
<thead>
<tr>
<th>Example Mission Functions</th>
<th>Example Community Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computing</td>
<td>Food</td>
</tr>
<tr>
<td>Security Forces</td>
<td>Water</td>
</tr>
<tr>
<td>Emergency Services</td>
<td>Shelter</td>
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<tr>
<td>Surveillance</td>
<td>Medical Care</td>
</tr>
<tr>
<td>Communication</td>
<td>Restoration</td>
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Will need to define either mission function or community service metrics for resilience analysis
Example Community Resilience Approach

1. Relate infrastructure points to critical services and determine level of service provided

2. Map out infrastructure points and existing energy supply infrastructure

3. Use distribution system information to refine location of potential microgrids/DERs

4. Assess portfolios of microgrids for cost versus societal burden to acquire critical services

5. Use the Microgrid Design Toolkit (MDT) to optimize technology selection and sizing for individual microgrids based on multiple metrics
Step 3.1: Define Resilience Requirements

• To move beyond considering only the electrical system to a more holistic view of resilience, planners should determine mission functions or community services provided by the location and whether they are critical, priority, or other.
  • Sandia’s guidelines will include a comprehensive list of potential mission functions and community services, each of which can be expanded out into the various levels of criticality.
  • Designs should always keep online buildings, systems, etc. associated with critical functions.

• Functions/services and their criticality may be different in daily operations versus emergency operations.
  • Use emergency plan to understand how usage will change in emergency situations.

• Each mission function or community service must have defined requirements for metrics in the resilience matrices below:

<table>
<thead>
<tr>
<th>Mission Function</th>
<th>Required Energy Availability</th>
<th>Max Allowable Outage Duration</th>
<th>Min Allowable Power Quality</th>
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Mission Resilience Matrix

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<tr>
<th>Service Type</th>
<th>Max Allowable Person Hours w/o Service</th>
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Community Resilience Matrix
Step 3.2: Assess Resilience Metrics

- Based on the functions/services determined in step 3.1, calculate the baseline values in the resilience matrix.
- For each thermal system needed to support mission functions, calculate the thermal system metrics for the building/system (degree days outside nominal and emergency targets).
- Metrics must be measured for each design bases threat/combination of threats.

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Community Resilience Matrix

Gaps between baseline metrics and requirements must be addressed in base case and alternative designs.
Step 3.2: Assess Resilience Metrics Cont.

Sample Tool Options

- Microgrid Design Tool (MDT)
- Resilient Node Cluster Analysis Tool (ReNCAT)
- System Master Planner (SMPL)
- Distributed Energy Resources Customer Adoption Model (DER-CAM)
- Renewable Energy Integration and Optimization (REopt)

Process

Threats

Direct Impact Model

System Model

Resilience Evaluation

Design Tools

Data Needs

- Fragility curves
- Infrastructure points and properties

- Building loads (thermal & elec.)
- Building functions
- Spatial info
- Supply system models
  - Spatial (network model)
  - Physical (volts/amps)
  - Operational (control/protection)
    - Economic operations (heat rate, etc.)
    - Emergency operations (mitigation & recovery)

- Ways to achieve services/functions
  - M of n requirements
Step 4.1: Determine Base Case Conceptual Design

• The base case will be the first conceptual design made to improve resilience
• Solutions will include traditional technologies
• The base case conceptual design can be used to meet resilience requirements
• Sandia will provide a comprehensive list of traditional technologies appropriate for this step of the process

Example Traditional Technology Options

• Local backup boilers
• Local backup generators
• UPS
• Fuel storage
• Strengthen overhead lines
• Replace overhead lines with underground lines
• Add extra systems to ensure n+1 local redundancy
Step 4.2: Analyze Base Case Conceptual Design

- Once the base case conceptual design is complete, compute all resilience metrics in the mission resilience matrix or the community resilience matrix.
- Compare base case resilience metrics to baseline resilience metrics.
- Base case must meet resilience requirements.
  - Meeting requirements may lead to high costs when using off-the-shelf technology options, particularly if including n+1 redundancy.

![Resilience by Mission Function](chart)

Base case design meets resilience requirements but may have high costs.
Step 5.1: Determine Alternative Design(s)

- Alternative designs will be developed to further improve resilience and/or decrease the cost as compared to the baseline and base case designs
- Solutions will include state-of-the-art technologies, and potentially optimal technology selection and placement within the system
- Sandia will provide a comprehensive list of state-of-the-art technologies appropriate for this step of the process

Example State-of-the-Art Technology Options

- Hot water and low temperature DH networks
- High temperature district cooling networks
- Efficient heat pumps
- Combined cooling, heat, and power (CCHP) with ad-/absorption cooling systems
- Power-to-heat
- Electrical and thermal storage systems
- Microgrids
- Waste heat
- Regenerative technologies
Step 5.2: Analyze Alternative Conceptual Design(s)

- Once the alternative conceptual design(s) is complete, compute resilience metrics in the mission resilience matrix or the community resilience matrix for each alternative design.
- Compare alternative design resilience metrics to baseline and base case resilience metrics for each alternative design.
- Also compare the resilience metrics of each alternative design to the required resilience metrics.

Alternative designs use new technologies and/or optimization to meet or exceed resilience requirements while minimizing cost.
Step 6: Select Design

- After the baseline, base case, and all alternative options have been designed and evaluated, select desired design based on comparison of metrics.
- Selected design becomes guideline for A&E firm.
Backup
Metrics of social burden:

- Effort required for people to satisfy their needs, divided by their overall ability
- Can be decomposed by different needs: shelter, food, water, etc.
- Can be discretized by city zone, district, census block, etc.

\[
B_C = \sum_{inf} \sum_{pop} \frac{E_{inf, pop}}{A_{pop}}
\]