Extreme Events and Grid Resilience

Los Alamos National Laboratory
Planning for Natural Disasters

Short-term
- Operational changes
- Crew and supply readiness
- Understanding potential impacts to supporting infrastructures

Long-term
- Exercises, including modeling hypothetical events
- Increasing maintenance programs
- Designing systems based upon risks
- Incorporating new technologies
Grid Resilience Requirements

• Translation of policy definition into a technical definition/specification
• Metrics for assessing resilience
• Right mixture of policy/regulation/financing to support resilience
• Modern tools to design, retrofit and operate power systems for resilience
  • Account for all-hazards
  • Operate at multiple spatial and temporal scales/resolutions
  • Support integration of emerging science and engineering
  • Beyond the standard restoration/recovery model
  • Supportive of cradle to grave cost benefit analysis
    • Engineering cost assessment
    • Economic impact assessment
Grid Resilience Assessment Tools at LANL

Energy system models for planning, design, and operation
- Network reliability (N-1, N-K)
- Control systems models
- Recovery/restoration models

Models to quantify metrics
- Demographics
- Economic impact models
  - Positive and negative GDP impact of grid component addition/loss

Opportunity to leverage 12 year $120M DHS investment in simulation and analysis tools and OE $2M/year investment in advanced grid analytics
Earthquake Damage Assessment

USGS ShakeMaps or higher fidelity models are used to determine spectral ground acceleration, displacement, and uncertainty information.
Flood Analysis

- Many types of flood events analyzed by characterizing the boundary condition
  - Over 100 studies
    - Dam/levee failure, river flooding, surge, tsunami
  - Adapting to watershed hydrologic analysis
    - Infiltration
    - Evaporation

Coastal “surge” boundary defined by NOAA SLOSH model output

High-resolution dam failure with known bathymetry

Ingest lower resolution NOAA tsunami marigrams for high resolution flood impact analysis
Electric Power Outage Risk Map

- Electric Power Outage Risk Map
  - Using NOAA 7-day wind forecast
  - Tested for hurricanes and tropical storms in 2012
  - Used for Hurricane Sandy

- Short-term
  - Incorporate into AGAVE
  - Step through time periods
  - Export contours as ESRI Shapefiles

- Long-term
  - Add severe weather watch areas
  - Incorporate precipitation (snow, rain)
  - Better damage/fragility estimates focusing on regional differences
Critical interdependencies among electric power, telecommunications, transportation, and emergency services intensify disruption to population, extend restoration times for all infrastructures.

Flood conditions can prevent access to areas.

Interdependency issues can occur days or weeks after the initiating event.
Grid Resilience Design and Operation Tool Requirements - Met

✓ Geospatially registered infrastructure (including grid) models to accurately represent the impact of extreme weather events on the grid (wind, water, fire, heat, ice and ground acceleration) and to accurately overlay multiple damaged infrastructures

✓ Models of infrastructure restoration to understand the constraints on grid restoration and the potential duration of outages

✓ Economic and population impact models coupled to power system outage models to provide a dollars-to-dollars basis for utility resilience investment decisions.

➢ Interdependence with natural gas pipeline networks to reveal the impact of extreme weather on the availability of natural gas to distributed generation
Grid Resilience Design and Operation Tool Requirements - Needed

- Interdependence with the transportation infrastructure to provide better estimates of grid restoration time
  - provides a basis for utility investment in spare component inventory management
  - Accounts for repair crew routing.
- Energy expansion/upgrade planning models that include risks from extreme weather and other events
- Advanced grid control models to estimate reductions in outages during grid restoration
  - distribution grid reconfiguration
  - aggregate microgrid models
- Real-time integration of data from existing and emerging sensors (AMI/OMS and traffic data) to improve restoration performance.
Past & Current R&D - Overview

Over 20 years of investment

All-Hazards

Hazard Damage Estimator
Energy Infrastructure GeoDatabase
Energy Network Model
Outage Area of Influence Model
Restoration/recovery Model
Economic & Population Impacts Model

Event Response Plans

Energy & Network Models

Minimize

Power Flow

Restoration Timeline

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EST. 1943

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Planned R&D Overview – Close the Resilience Design Loop

- Develop and deploy of resilient system design and operation tools
  - Full cost benefit analysis of investment decisions
  - Account for interdependencies between power distribution, natural gas and transportation systems
  - Multi-level optimization techniques
  - Run-time performance improvement to promote full value of optimization

Economic & Population Impacts Model
Restoration/recovery Model
Outage Area of Influence Model
Energy Network Model
Design and Operational Requirements, Plans & Procedures
Investment Decisions ($)
Hazard Damage Estimator
Energy Infrastructure GeoDatabase

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Planned R&D Overview – Adapt Existing Tools to Grid Resilience

Adapt existing damage analysis system to distribution scale problems

- Probabilistic damage assessment
- Engineering cost estimator for hardening distribution systems
- Data structure for distribution system data

- Economic & Population Impacts Model
- Investment Decisions ($)
- Design and Operational Requirements, Plans & Procedures
- Hazard Damage Estimator
- Outage Area of Influence Model
- Energy Infrastructure GeoDatabase
- Energy Network Model
- Restoration/recovery Model
Planned R&D Overview – Incorporation of New Models & Solvers

- Apply transmission scale interdependency models to distribution grid solvers
  - Hooking into GridLab-D, OpenDSS
- Integrate microgrid models to improve outage area influence model
- Apply multi-level optimization tools at the distribution scale
  - 4 years algorithm development with extensive peer review
  - Transportation scheduling/routing model
  - Electrical grid/generation model

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Figure 1: A MIP Model for the Unserved Load.
Current Practice & Planned R&D – Transportation Interdependency

Current State of Practice
- RestoreSims integrates:
  - Grid, Gas
  - Transportation, Crew scheduling
  - Repair component inventory
  - Repair component warehousing
- Reveals impact of transportation and inventory constraints on restoration
- Enables utilities to design
  - Repair component inventory
  - Component warehousing
- Capability outperforms utilization based restoration practice, e.g. prioritizing based on pre-event utilization

Planned R&D
- Adapt to distribution grid models
- Convert to an operational tool

Restoration Progression on 67 Asset Repair Scenario
Current Practice and Planned R&D – Gas-Grid Interdependency

Current Practice
- RestoreSims integrates:
  - Grid, Gas
  - Transportation, Crew scheduling
  - Repair component inventory
  - Repair component warehousing
- Reveals impact of gas infrastructure damage on restoration
- Reveals cross-utility vulnerabilities prioritizing based on pre-event utilization

Planned R&D
- Adapt to distribution grid models
- Add models of DG and microgrids
- Convert to an operational tool
Superstorm Sandy Example

Example focuses on potential expansion options to minimize impacts of loss of the East 13th Street Substation, which outaged lower Manhattan.

Economic Loss $196,484,000 GDP/day
Potential value of adapted resilience framework

• Expansion options evaluated
  • Single large microgrid
  • Multiple distributed microgrids
  • Transmission expansion
  • Combinations of the above

• All options reduce the impact of outage event relative to current system

• For this scenario, expansion using line and microgrid provides best early results

A closed loop decision tool (including engineering cost and economic benefit) will help decisions on which option to pursue
Summary

Planning for disasters includes:

- Understanding natural threats to infrastructure systems
- Preparing for a disaster
- Incorporating infrastructure dependencies into restoration
- Recovering quickly following a disaster
- Developing more resilient systems
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