Resilient Energy Systems
Mission Campaign

DEVELOPMENT OF POWER SYSTEM MODELS FOR OPTIMAL GRID RESTORATION SUBJECT TO INTENTIONAL THREATS

This project brings together an array of modeling techniques to develop improved methods for restoring the electric grid from a complete or partial disruption, especially disruptions resulting from an intentional threat, which may limit or compromise situational awareness and grid control.

THE CHALLENGE

For the nation to be resilient, we must understand how intentional threats will impact our power grid, especially how the grid is restored from partial or complete disruptions considering intentional threats. Previous research has focused on two paths. On intentional threats, research has been limited to determining the extent of outages potentially caused by intentional threats. In grid restoration, the approach has been to subdivide the restoration problem into a series of sub-problems, dealing with black start, crew dispatch, and other issues as individual problems.

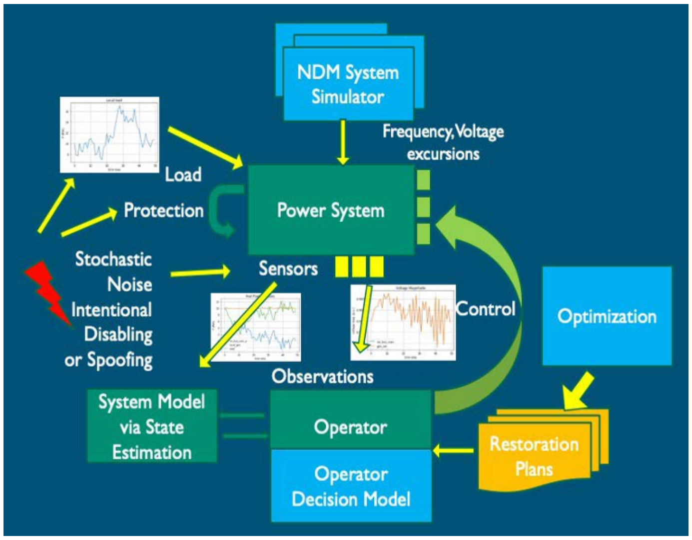
The state of the art in restoration techniques, while appropriately treating the grid as an alternating current (AC) system rather than as a direct current (DC) approximation, nonetheless assumes there is full observability and control of the grid, implying the network is in a known state. When a power grid is subject to intentional threats, however, observability and control may not be complete, and the state of the system is described as uncertain at best. Modeling of the grid and restoration must account for these uncertainties.

This research project focuses on creating and testing new models of power system restoration after a large-scale outage has occurred, utilizing a wide array of modeling techniques to address individual portions of the restoration problem, while bringing these methodologies together to solve the overall problem. This research represents a significant advancement in our ability to estimate the duration of grid outages and develop restoration action plans.

APPROACH

The project seeks to leverage research in two directions. In one direction, we seek to build on success in the last decade in network dynamic modeling (NDM) of other subsectors of the energy sector (petroleum fuels, natural gas) to capture behaviors of the electric grid under restoration at higher levels of abstraction than traditional grid modeling methods.

In the other direction, we focus on extending and enhancing state-of-the-art optimization techniques to incorporate a family of intentional threats (e.g., cyberattacks to control systems, kinetic attacks, electromagentic pulses).

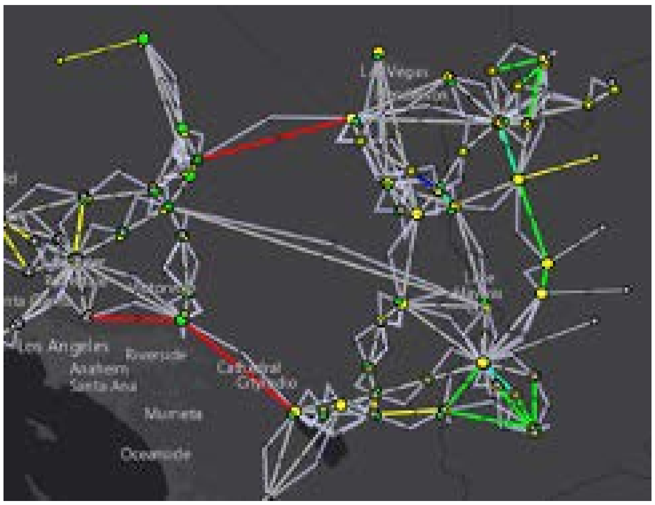


Modeling components (in blue) relative to network and control configuration and information flows.

Together, these techniques will enable the development of dynamic optimization of grid restoration subject to intentional threats. Restoration from these types of events is difficult to model because of the limited amount of case data on power outages lasting more than 24 hours and virtually no data on long-duration outages due to intentional threats. Taking this technically different approach accomodating multiple modeling techniques, this project will capture a wider breadth of phenomena to aid in restoration of the electrical grid.

EXPECTED RESULTS

Expected results from the research will be new, validated algorithms for grid restoration that will be implemented in software. The newly updated software will aid in modeling grid restoration when it is subject to intentional threats and attacks. We also expect to deliver at least three peer-reviewed publications.



Network dynamic model of IEEE RTS-96 system

The simplified and efficient network dynamic model developed through this research will allow more comprehensive coverage of the space of scenarios considered in resillience analyses. Because large-scale events are rare, and each is a product of singular contingencies, historical cases present a very incomplete picture of the space of possibilities. A simplified, stylized representation will create the option to trade accuracy in the representation of individual cases for breadth in the space of cases considered. A paper describing the model and comparing it to more traditional techniques will foster its use in other power system resilience studies.

The improved optimization modeling within this work has several features. These include consideration of the restoration problem as a whole rather than as individual parts, the incorporation of dynamic system behavior, and consideration of the uncertainties involved in the existence of intentional threats and situational awareness that might persist into restoration. Application of these new optimization techniques will result in more accurate restoration estimates relative to the current state of the art, and will improve the ability of utilities utilizing these techniques to avoid the unintended consequences of intentional threats in the restoration of the grid from a failed state.

The research is further expected to produce a new model of operator decision-making under conditions of limited information and high uncertainty. This model, when combined with power system simulation capabilities and new recovery optimization techniques, will allow the program to potentially identify new kinds of vulnerabilities, and to propose new resilience strategies that have been tested against a broad range of scenarios that are robust to potential corruption of operators' situational awareness. The operator model can make important contributions in other research and engineering work, and will be published to enable those contributions.

EXPECTED IMPACT OF THIS RESEARCH

The expected impact from this research will be to fill in major gaps for the Department of Energy Office of Electricity, the Department of Defense, and the Department of Homeland Security's Cybersecurity and Infrastructure Security Agency. Methods and tools developed from this project will allow Sandia to characterize the benefits of new technologies that are designed to improve the grid's resilience. Collaboration efforts with the Department of Energy's North American Energy Resilience Model will be strengthened. This capability will improve national security by understanding and reducing long-duration outages at critical national security facilities.

RESILIENT ENERGY SYSTEMS

Sandia's investment in this project is part of its Resilient Energy Systems portfolio of projects, coordinated R&D that addresses the resiliency of the nation's energy systems and other critical infrastructures to threats. This project connects to the *System-Level Threat-Informed Computational Science* research thrust, with the objective of developing new computational capabilities to improve system response to intentional threats.

CONTACT:

resilience@sandia.gov