Author's Accepted Manuscript

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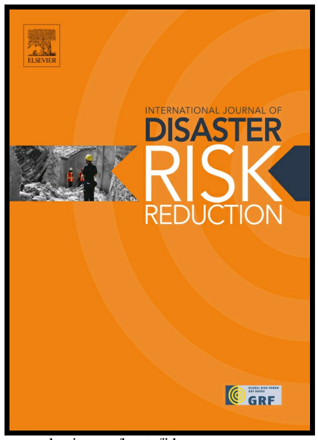

www.elsevier.com/locate/ijdr

PII: S2212-4209(16)30079-6
DOI: http://dx.doi.org/10.1016/j.ijdrr.2016.06.008
Reference: IJDRR370

To appear in: *International Journal of Disaster Risk Reduction*

Received date: 23 February 2016
Revised date: 22 June 2016
Accepted date: 23 June 2016

Cite this article as: Arun Veeramany, Stephen D. Unwin, Garill A. Coles, Jeffery E. Dagle, David W. Millard, Juan Yao, Cliff S. Glantz and Sri N.G. Gourisetti, Framework for Modeling High-Impact, Low-Frequency Power Grid Events t Support Risk-Informed Decisions, *International Journal of Disaster Ris Reduction,* http://dx.doi.org/10.1016/j.ijdrr.2016.06.008

Framework for Modeling High-Impact, Low-Frequency Power Grid Events to Support Risk-Informed Decisions

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***Abstract* — Natural and man-made hazardous events resulting in loss of grid infrastructure assets challenge the security and resilience of the electric power grid. However, the planning and allocation of appropriate contingency resources for such events requires an understanding of their likelihood and the extent of their potential impact. Where these events are of low likelihood, a risk-informed perspective on planning can be difficult, as the statistical basis needed to directly estimate the probabilities and consequences of their occurrence does not exist. Because risk-informed decisions rely on such knowledge, a basis for modeling the risk associated with high-impact, low-frequency events (HILFs) is essential. Insights from such a model indicate where resources are most rationally and effectively expended. A risk-informed realization of designing and maintaining a grid resilient to HILFs will demand consideration of a spectrum of hazards/threats to infrastructure integrity, an understanding of their likelihoods of occurrence, treatment of the fragilities of critical assets to the stressors induced by such events, and through modeling grid network topology, the extent of damage associated with these scenarios. The model resulting from integration of these elements will allow sensitivity assessments based on optional risk management strategies, such as alternative pooling, staging and logistic strategies, and emergency contingency planning. This study is focused on the development of an end-to-end HILF risk-assessment framework. Such a framework is intended to provide the conceptual and overarching technical basis for the development of HILF risk models that can inform decision-makers across numerous stakeholder groups in directing resources optimally towards the management of risks to operational continuity.**

***Index Terms*— Cyber, Cyclones, Earthquakes, Hurricanes, Power Grids, Risk Analysis, Terrorism, Risk Management**

I. BACKGROUND

Natural and man-made hazardous events resulting in the simultaneous loss of multiple grid infrastructure assets challenge the electric power grid's security and resilience. However, the planning and allocation of appropriate contingency resources for such events requires an understanding of their likelihood and the extent of their potential impact. Where these events are of low likelihood, a risk-informed perspective on planning can be problematic as there exists an insufficient statistical basis to directly estimate the probabilities and consequences of their occurrence. Since risk-informed decisions rely on such knowledge, a basis for modeling the risk associated with high-impact low frequency events (HILFs) is essential. Insights from such a model can inform where resources are most rationally and effectively expended. The present effort is focused on development of a HILF risk assessment framework. Such a framework is intended to provide the conceptual and overarching technical basis for the development of HILF risk models that can inform decision makers across numerous stakeholder sectors.

The North American Electric Reliability Corporation (NERC) Standard TPL-001-4 (NERC, 2014) considers events for transmission reliability planning. The planning criteria includes consideration of severe events, such as the simultaneous loss of multiple co-located assets, but does not address events of such severity that they have the potential to fail a substantial fraction of grid assets over a region, such as geomagnetic disturbances, extreme seismic events, and coordinated cyber-physical attacks. These are beyond current planning guidelines. As noted, the risks associated with such events cannot be statistically estimated based on historic experience; however, there does exist a stable of risk modeling techniques for rare events that have proven of value across a wide range of engineering application domains.

The value of a risk model is reflected in the degree to which it can be exercised to provide insight to stakeholders and decision-makers, and in the process by which it is maintained as an evergreen and continually improving model of the domain it represents. Elements of risk management include the modeling, evaluation of management options based on interrogation of the model, implementation of the selected options, communication of strategy and actions to stakeholders, and monitoring new data and insights to update the model as appropriate. The framework defined here is focused on the means of developing the underlying risk model.

There is an active and growing interest in evaluating the value of risk management techniques in the transmission planning and emergency response communities, some of this interest in the context of grid modernization activities. The availability of a grid

This work was supported by the U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability under the Contract DE- DE-AC05-76RL01830

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