Characterizing Risk of Cascading Blackouts to Multiple Contingency Events

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Summary

We present a methodology for characterizing the risk of a power grid configuration to cascading blackouts in the presence of multiple simultaneous outages. We use the *Random Chemistry* algorithm to find interacting subsets of these so-called "malignant" branch outages on a blackout simulator. We then use empirical techniques to estimate the risk of the grid to blackout. This risk metric can be used in long-range and day-ahead planning to shape policy and help mitigate cascading failures.

Background

The North American Electrical Reliability Corporation (NERC) requires power grid operators to perform so-called *n-1 contingency testing*. This analysis consists of running simulations of the power grid in which one branch at a time is removed to verify that a cascading blackout would not ensue as a result of this single outage. The NERC has recently implemented new guidelines that require that the grid be robust to cascading blackouts even if more than one outage occurs at a given time. This *n-k contingency testing* is a computational challenge because of the combinatorial search space that must be explored with $\binom{N}{k}$ ways that a k-way outage is possible.

Methods

We use a cascading blackout simulator as described in [1] and the *Random Chemistry* algorithm to find a sufficient subset of components that, when removed from the grid, result in a cascading blackout. We estimate the full set of these *malignant subsets* using nonlinear least squares regression on an inverse exponential curve relating the number of malignant subsets seen to the number of those that have been seen for the first time. We then characterize the subset of branches that have been found with a risk statistic based on an estimate of the joint probability that a given malignant subset of branches might be tripped due to an event extrinsic to the system. This can then be used to evaluate the total risk of the grid configuration to cascading blackouts.

Polish Grid Blackout Simulation

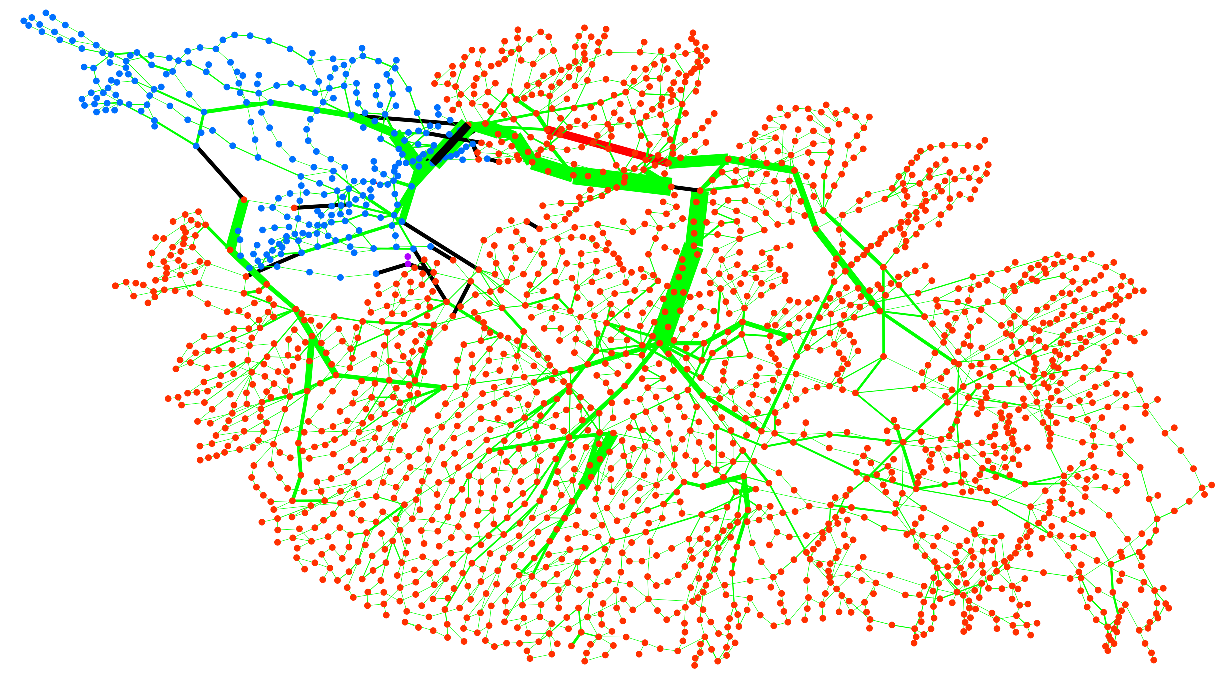

Figure : Each node in the plot is a bus in the Polish grid and branches are represented by edges in the graph. Different node colors show separated sections of the grid due to outages.

Results

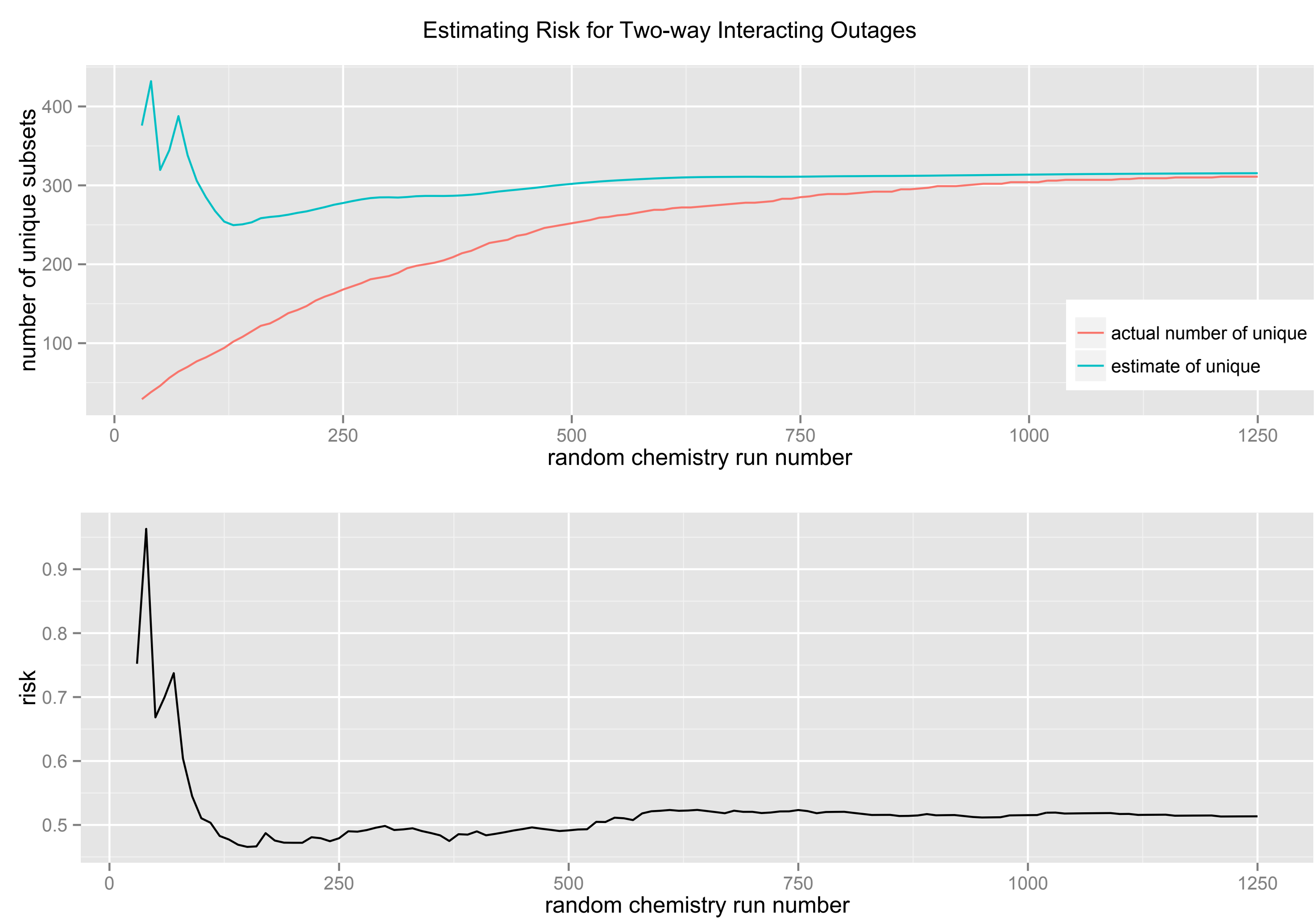

Figure : Above: Plot of actual number of unique malignant subsets found (pink) and estimated number of otal unique such subsets (blue) as Random Chemistry trials are run. Below: Plot of respective risk estimate

Random Chemistry Algorithm

We wish to detect which of *k* subsets of branch outages interact to result in a cascading failure of the power grid. The Random Chemistry algorithm allows us to winnow down from a large subset of components that we know cause a blackout to a minimal such subset that causes a cascading blackout event. The algorithm consists of first picking a random large set of branch outages that cause a cascade. From this set, a fractional subset is chosen and tested for whether it causes a cascade. If it does not, a new random set of the same size is chosen and tried. If it does cause a cascade, the process of picking a smaller subset from this set continues until a predefined small subset is found. From this subset, exhaustive search is performed to find a minimal branch subset (minimal in the sense that no smaller subset can be found that causes a cascade).

Discussion

We obtained a risk metric for two-way interacting subsets of branch outages using the methods described. The results can be seen in Figure 1. The estimated number of total unique branch outage subsets can be seen in blue compared with the number of actual unique subsets found in pink. The plot of estimated risk as new Random Chemistry iterations are run can be seen to settle on a steady risk value before having obtained the full set of unique malignant subsets. In future work we will apply this metric to larger subsets of interacting outage combinations.

References

- Eppstein, Margaret J and Hines, Paul DH, *A Random Chemistry Algorithm for Identifying Collections of Multiple Contingencies That Initiate Cascading Failure*, Power Systems, IEEE Transactions on, 2012

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