PROFILINGBLACKOUTS - Summary report

The need to reduce CO2 emissions is fundamentally changing the way the electricity grid is being operated and planned. Renewable generation sources such as wind power and solar panels are both less predictable and less controllable than conventional generators. In order to incorporate these sources without excessive costs to society it is necessary to operate the grid in a smarter way to make more efficient use of the network resources. The potential benefits of this 'smart grid' transformation are large and well-studied, but it is not clear what this will mean for the reliability of the electricity supply.

The PROFILINGBLACKOUTS project aims to use advanced statistical tools to assess and improve the reliability of the electricity grid, with a particular focus on high-impact low probability events. A prime example of such events are cascading outages, where an initial outage triggers follow-up outages thus leading to large-scale blackouts. The chances of such an event occurring are vanishingly small so these events are easily overlooked. However, the impact is so significant that the possibility of such an event must not be ignored.

We have developed models and methods that aid researchers and system operators with the identification and characterisation of such risks. When complexity of the network prevents precise characterisation of the risk profile, the methods provide robust bounds that reflect this lack of information. In addition, the project has investigated stochastic methods for preventing large-scale blackouts by enlisting domestic refrigerators for the stabilisation of the grid. Three main outcomes of the project are described below.

Minimal model for the analysis of cascading outages in generic networks

A minimal model has been developed for the simulation and analysis of cascading outages in electricity networks. Such a model provides insight into general drivers of cascading outages. In contrast to existing cascading models in the scientific literature, this model takes into account key elements of realistic electricity grids. In particular, it reflects the physical flow of electricity through the network (DC power flows) and the prevalent 'N-1' security standard that requires resilience against single component failures. The model enables random generation of networks, which can be used to study the impact of design parameters on performance, without being tied to any particular network configuration.

Investigating the properties of rare events such as cascading outages requires the analysis of many possible scenarios and tends to be limited by available computing power. We have developed a computationally efficient power flow simulator that is specifically targeted for fast re-computation of flows after sequential component failures. The combination of a random network generator and efficient sampler make it possible to accurately quantify the cascading properties of networks. This is providing new insight into the relations between network design parameters and robustness against cascading. Because of its efficiency, the cascading power flow simulator has already been used in a project that focuses on the reliability of protection measures.

Robust statistical analysis of observations

A recurring problem in the analysis of rare events is that one must infer their properties from a very limited number of observations. Further complicating matters, in some cases rare events are known to be a possibility although they have not been observed at all. Computer simulations of cascading outages suffer from both of these problems, and existing methods for estimating the properties of the model from these simulations are not sufficiently reliable.

As part of the project we have developed a robust approach to the analysis of such data sets that makes only minimal assumptions on the size of the dataset or the properties of the process that generated them. The defining feature of this method is that it produces estimates for any event of interest (e.g. the mean size of an outage) with strict reliability bounds. For example, it is able to give an interval for the true value of the mean with at least 99% accuracy, regardless of the underlying model.

This is achieved by combining probabilistic (Bayesian nonparametrics) and so-called 'imprecise' (interval probability) analysis. The resulting method allows for a very straightforward numerical implementation, which makes it suitable for use as a generic 'black box' data analysis method. It has a wide array of potential applications in critical systems engineering, but also in natural sciences and finance.

In the coming year, the method will be used for the analysis of measurements from the Low Carbon London smart grid demonstrator project. Robust analysis of these and other demonstrator projects in the UK and beyond is required to look beyond the statistical fluctuations in these necessarily limited trials. It is critical to use the data to the fullest extent possible, because the learnings from these trials will inform future smart grid standards in the UK and Europe.

Stochastic control of domestic refrigerators for reliability services

A third research activity concerns the intelligent control of electrical load to increase the reliability of the network. Large numbers of refrigerators (and similar loads such as A/C units and electric heaters) are connected to the grid at all times, and together these represent a substantial electrical load. Because the temperatures of such appliances change only gradually they are in principle able to temporarily reduce their power consumption when the system is under stress, and restore their temperatures at a later time. Such flexibility can provide large gains in system reliability at very little cost and with negligible impact on the quality of service of the appliances.

Although conceptually straightforward, it has proven difficult to design an appropriate controller for this service provided by a large group of thermal appliances. In recent years many control schemes have been proposed, but each of these has either sacrificed refrigerator performance, lacked real controllability or required a complex real-time communication infrastructure.

We have developed a novel stochastic control approach that does not suffer from these issues. The only prerequisite is that appliances share a reference power curve (the desired response). Each appliance then controls its power consumption in such a way that it reproduces the reference curve *on average.* For a large population the fluctuations due to individual appliances will average out and the desired aggregate response prevails.

Our decentralised control method offers exciting possibilities for the provision of energy and reliability services by domestic thermal appliances. It can be integrated into appliances by manufacturers or service aggregators, who may then provide services to transmission system operators and – in the smart grid future – the distribution network operators. Furthermore, the insight gained in our studies will also be used to inform the discussions regarding future network standards (in Europe the ENTSO-e Demand Connection Code).