Development of efficient assessment methods of power system resilience enhancement

Context

The N-1 security rule has been traditionally used to design, plan and operate power systems. Although such a criterion ensures high levels of security of electricity supply, resulting power systems might still be vulnerable to extreme events such as tornadoes, earthquakes, snowstorms, wildfires, etc. Though the probability of occurrence of such extreme events is usually low, they could lead to catastrophic consequences. It implies that the risk of unsupplied energy associated with those High-Impact, Low-Probability (HILP) events is high. Consequently, it is critical to ensure that power systems are resilient, in order to minimize the consequences, and thus the risk, entailed by these HILP events. The resilience of a power system can be formally defined as its "ability to limit the extent, severity, and duration of system degradation following an extreme event". A 4-step approach to assess the resilience of power systems is usually proposed: (i) threat characterization – what are the threats to my system and their likelihood?, (ii) system vulnerability – how well can the elements of my system resist the threat?, (iii) system reaction – what is the impact on my system?, and (iv) restoration process – how fast can I restart normal operation? The current proposal focuses on seismic events as an example of threat characterization –even though the methodology proposed could be straightforwardly adapted to other types of threat – and on their impact on distribution power systems, characterized by radial grids.

Previous work

The threats are characterized by the Peak Ground Acceleration (PGA), whose probability density function (pdf) is elicited from field data. The failure probabilities of the various grid elements as a function of the PGA are modelled by fragility curves, corresponding to the cumulative distribution function (cdf) of the PGA causing the failure of each specific element. A commonly used resilience indicator for power systems is the Expected Energy Not Served (EENS). In an ongoing master thesis (N. Evenepoel, IrEM 2022), the restoration process has not been considered. Indeed, the objective has been to develop an efficient estimation method of the grid resilience, in order to compare, within limited computation times, the loss of performance of the grid, and the impact of various modifications of the grid on this possible loss. Therefore, the expected impact of the event must be seen as the Expected Power Not Served (EPNS). Estimating the EPNS can result from a Monte Carlo sampling of the pdf of the threat. The contingency caused by the sampled event is defined by sampling the fragility curves, and the resulting loss of energy supply is then assessed. When dealing with HILP events, however, this simple Monte Carlo scheme turns out to be computationally inefficient. Alternative sampling algorithms are studied, a.o. stratified sampling for which two definitions of the strata are proposed. An alternative approach to Monte Carlo sampling has been developed, observing that the loss of energy supply is independent, for a given contingency, of the magnitude of the threat. Starting from a purely radial grid and adding step-by-step additional features, an algorithm allowing for an exact estimation of the EPNS based on the computation of simple integrals has been proposed. It provides a way of performing a sensitivity analysis of the EPNS to the load distribution at the time of occurrence of the event, with almost no additional computational effort.

Objective

The proposed master thesis will contribute to further developing this resilience assessment algorithm, in several directions: * Adapting it to the assessment EENS, by including priorities in repairs and restorations of grid elements * Accounting for variable load profiles and intermittent generation * Optimizing grid modifications to enhance its resilience * …

Prerequisite

The course "Electric Power Systems I" is an important prerequisite (with a minimum mark of 14/20), but it can be followed in parallel with the MSc thesis (e.g., for students in Engineering Physics).

Contact person

For more information please contact : pierre.etienne.labeau@ulb.be, pierre.henneaux@ulb.be