PhD Proposal 2017

School: École CentraleSupélec – Université Paris-Saclay	
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Collaboration with other partner during this PhD: In France:	In China:

Title: Advanced computational methods for the probabilistic risk assessment of electric power systems, considering natural hazards and extreme weather conditions
Scientific field: Risk Assessment, Computational methods, System Modeling and Simulation, Complex Safety-Critical Power Systems, Extreme Events, Natural Hazards
Key words: Risk Assessment, Electric Power Systems, Mathematical (Risk) Models, Uncertainty Analysis, Sensitivity Analysis, Monte Carlo Method, Efficient Simulation Techniques, Meta-models, Extreme Events

Details for the subject:

1. Background, Context:

Extreme events and weather conditions can cause natural disasters that can impact Critical Infrastructures (CIs) such as electric grids, energy and water supplies, communication systems and transport routes, and at the same time put a strain on emergency and crisis response capabilities, and trigger accidents at several installations at the same time. In addition, more than one hazard may appear at the same time (e.g., heavy winds and precipitation) and one natural hazard can trigger others (e.g., earthquake followed by a tsunami). Also, recent studies predict that climate change will lead to more frequent and more intense natural disasters, often in areas where there are large industrial facilities and infrastructures.

In this context, we look at electrical power systems, which represent a vital infrastructure for modern society and consider Probabilistic Risk Assessment (PRA) as a way to address the risk problem, under the conditions of natural hazards and extreme weather conditions: the objective is to estimate the probability (or frequency) of disturbances to power system operation and their consequences [McCalley et al., 2004].

The existing power grids have been developed to meet the requirements of conventional single direction power delivery from centralized high-capacity generation units (e.g. thermal plants, nuclear power plants, etc.) to various end-user loads (e.g. industry, commerce, residence, etc.). However, the energy challenges faced by Europe and the rest of the world are changing the landscape of power systems: for example, renewable energy sources (such as photovoltaic panels and wind turbines), often geographically separated from the traditional power sources, are increasingly integrated into the distribution network.

In this view, environmental conditions can strongly influence the operation and performance of future generation and distribution systems for several reasons. First, the growing shares of renewable-energy generators installed inject considerable amounts of (aleatory) uncertainty into power system operation: actually, owing to the inherently random nature of the corresponding natural resources, renewable-energy generators behave quite differently from conventional ones. In addition, these systems employ relatively new technologies, which introduces a significant amount of (epistemic) uncertainty due to lack of knowledge and/or data on the physical phenomena involved and/or to limited or (possibly) null operating experience of the corresponding components or systems over the wide range of conditions encountered during operation. Finally, several intrinsically stochastic environment-related contingencies (e.g., high winds, thunderstorms, heavy snows, or even earthquake and flooding events) can damage or deeply degrade the components of the power grid [Rocchetta et al., 2015]. The presence of all these uncertainties puts pressure on decision makers in two directions: (1) to robustly assess the risk associated to the modern power production and distribution systems; (2) to identify by sensitivity analysis those (uncertain) “internal” system elements and “external” environmental contingencies that contribute the most to system risk, with the objective of properly driving resource allocation for uncertainty reduction and consequent confidence gain for design, maintenance and operation decision making.

In practice, real-world power production and distribution systems are: (1) dynamic, i.e., their state changes (deterministically and/or stochastically) in time; (2) hybrid, i.e., they are characterized by both discrete and continuous variables (e.g., components’ discrete states, like functioning, failed, standby, and continuous physical quantities, like temperatures and power flows); (3) complex, i.e., they are described by a large number of variables and parameters related by highly nonlinear dependences. As a consequence of these characteristics, the risk associated to such systems cannot be assessed analytically. Instead, in current PRA practice the operation of a power system and the undesired chains/sequences of events (scenarios) possibly leading to its disturbance and/or failure are generally simulated using computer models. In more detail, the scenarios and the corresponding probabilities and consequences are generated and estimated, respectively, by repeatedly randomly varying the (uncertain) operating conditions of the system. This approach is referred to as Monte Carlo (MC) simulation.

While MC simulation makes it possible to assess the risk related to a complex power system, it presents some drawbacks. First, the necessity to introduce the time dimension into the analysis leads to a dramatic increase in the number of possible scenarios, which makes their thorough exploration impossible in practical cases. Furthermore, when an accident scenario of interest is very rare (which is typically the case in the presence of extreme events and weather conditions), a large number of simulations must be carried out to estimate the probability of that scenario with sufficient statistical accuracy and precision. Finally, the computational cost associated to the simulation of the complex power system behavior can be very high (e.g., it may take hours or even days in some particular applications) [Perez et al., 2011]. This calls for advanced simulation techniques that allow performing efficient and robust risk assessment and sensitivity analysis for innovative power production and distribution systems, in the presence of “extreme” events and weather conditions, while reducing the associated computational cost.

2. Research subject, work plan:

The PhD student will tackle the issue of performing efficient and robust risk assessment and sensitivity analysis of electric power systems, in the presence of “extreme” events and weather conditions. This will be done by developing innovative solutions in two directions. On one side, advanced MC simulation methods (e.g., Adaptive Importance Sampling [Botev et al., 2013] and entropy-driven techniques [Hu, 2005]) will be used to efficiently and intelligently probe the space of the (undesired) event sequences in a complex, dynamic power system with the objective of providing accurate and precise risk (i.e., probability-consequence) estimates and possibly to extract useful sensitivity insights with a limited number of simulations. On the other side, cheap-to-evaluate surrogate models (also called response surfaces or meta-models) will be “trained” to reproduce the behaviour of the original, expensive-to-evaluate computer model: then, they will be employed to replace the original system model code in the power system risk assessment and sensitivity analysis. Examples are represented by Gaussian process models [Marrel et al., 2015], Polynomial Chaos Expansion [Kersaudy et al., 2015] and Stochastic Collocation methods [Ng and Eldred, 2012].

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