Quantitative all-hazard risk assessment of power transmission systems using contingency-constrained optimization

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Motivation

- Critical infrastructure is vulnerable to various hazards and threats that can result in the failure of one or multiple components, endangering the stable operation of the system.
- According to EU Regulation [1], the competent authority of each Member State should submit a risk-preparedness plan including national, regional, and bilateral measures to prevent, prepare for and mitigate electricity crises.
- There is a need for an all-hazard, integrated assessment of risk and resilience to assess the impact of natural hazards and man-made threats on electric power systems.

Focus on HILF Events

- Use method for probabilistic modeling of high-impact, low-frequency events proposed by PNNL [2]
- Stratified random sampling of events triggered by natural hazards and malicious attacks (Monte Carlo method)

Hazard and Threat Modeling

- Use realistic **parametric models** for various hazards and threats

Hazard/Threat	Stressor	Initiating event (random parameters)
Earthquake (E)	Peak ground acceleration (PGA)	magnitude, location and depth of hypocenter
Hurricane (H)	Peak gust wind speed (PWS)	magnitude (max. wind speed), track (straight line defined by two points within the area)
Kinetic attack (K)	Explosives (transformers)	magnitude (threat level), number of attacked assets
Cyber-attack (C)	Data breach (open all breakers at substation)	magnitude (threat level), number of attacked assets

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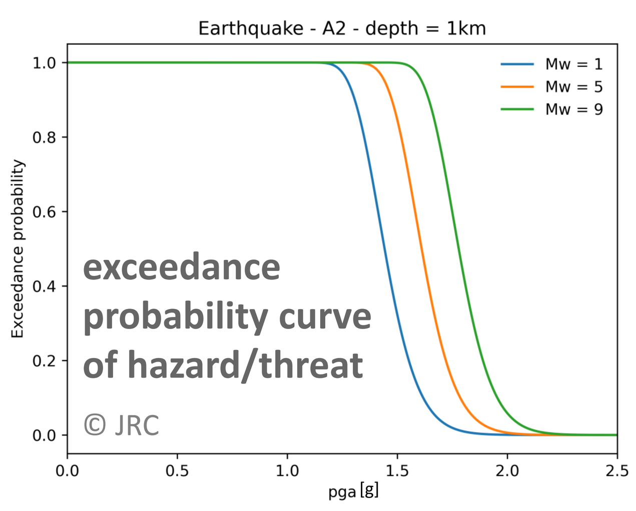
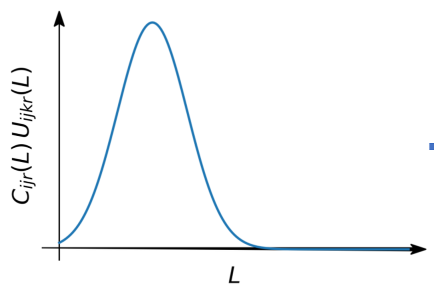
- Draw parameter values from **probability distributions** based on historic data (earthquakes, hurricanes)

→ Latin Hypercube Sampling (LHS)

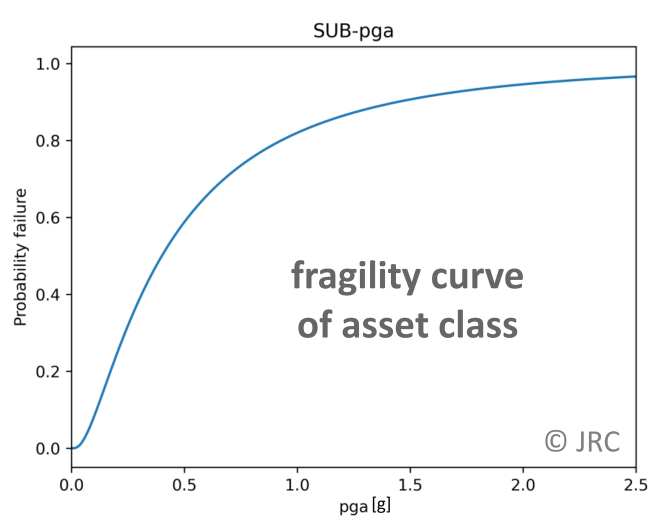


Convolution



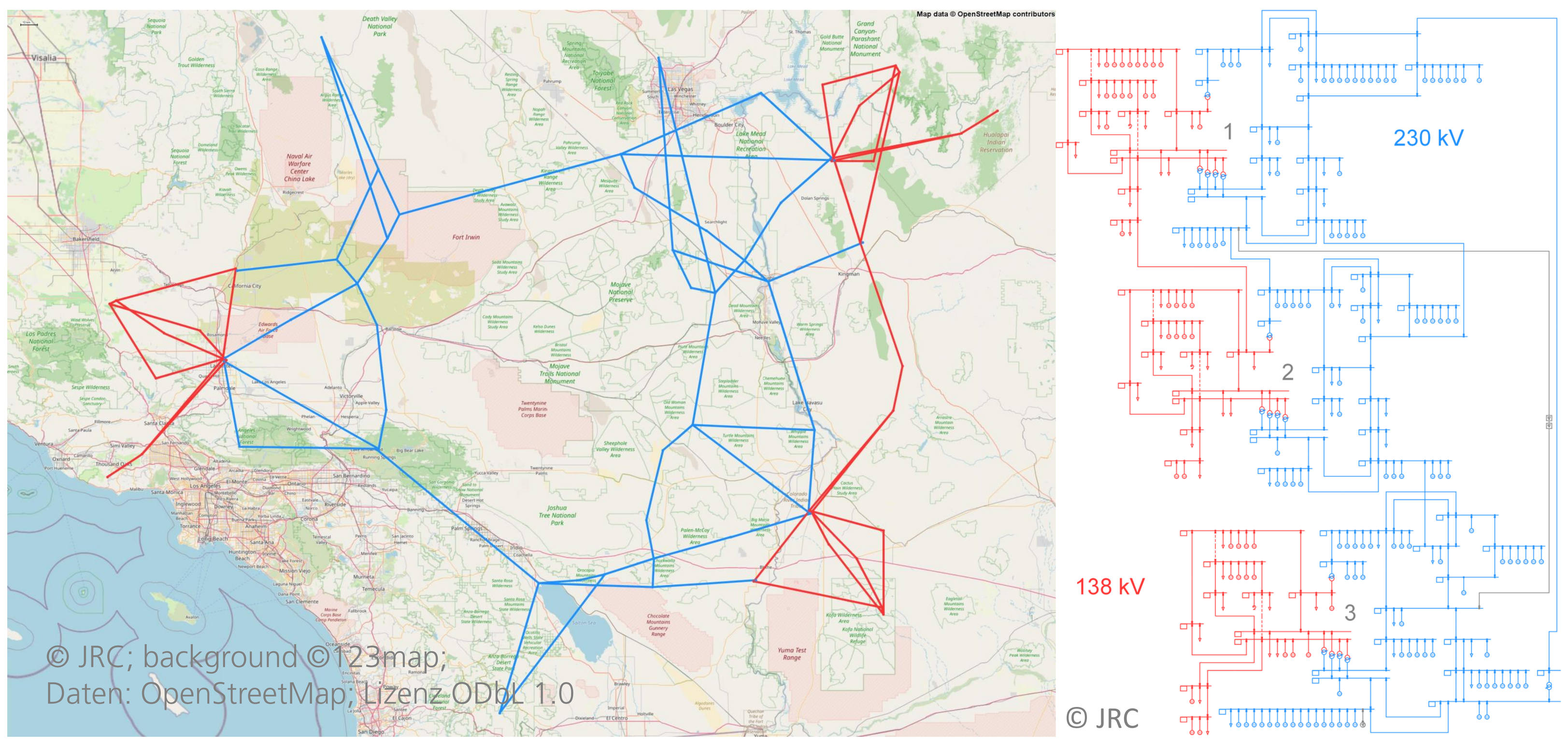
event's transfer of stressor load to asset

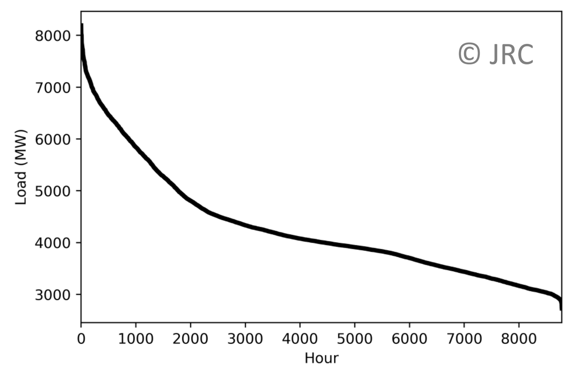
- Each component characterized by hazard-specific **fragility curve** [2]
"Capacity to withstand stressor"



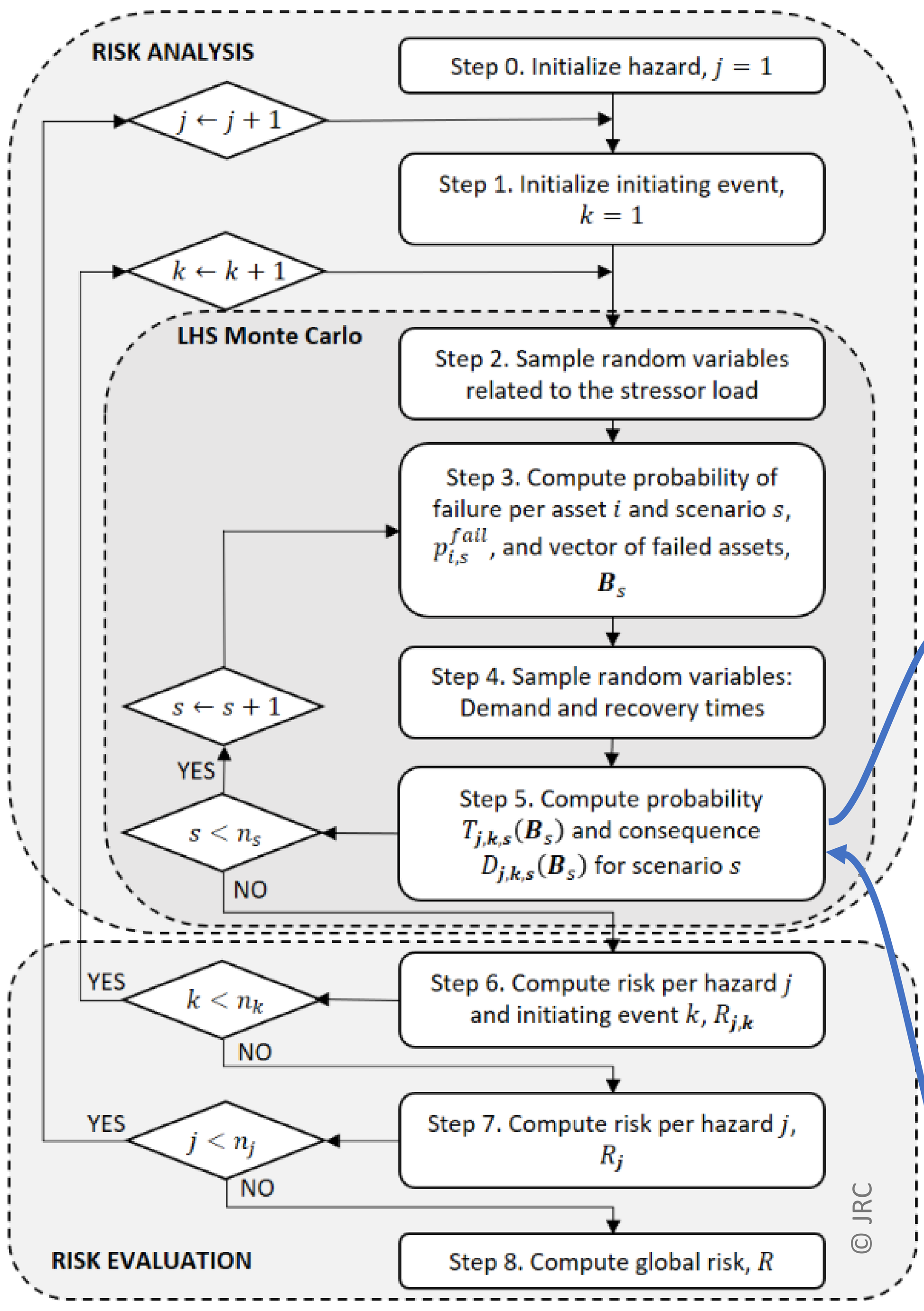
Demo Application

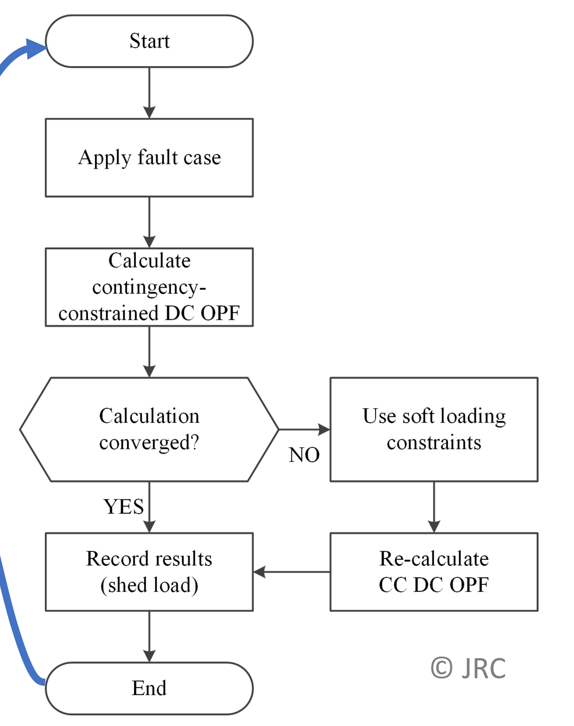
- IEEE RTS-GMLC grid model, implemented in PowerFactory® [6]





Load-duration curve



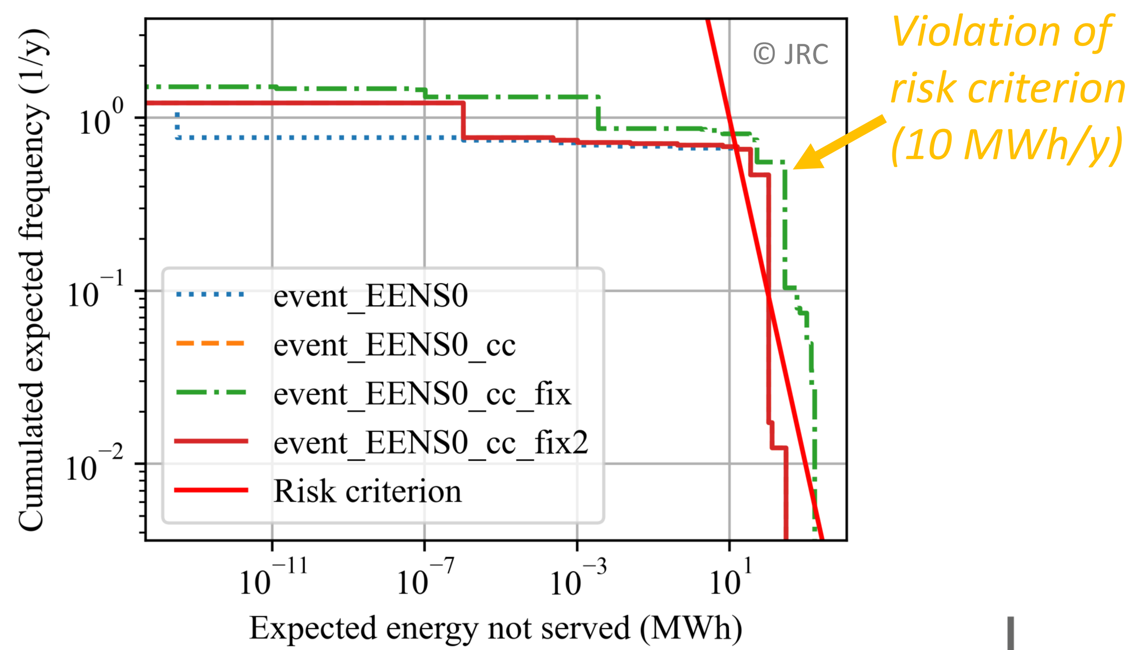


Monte-Carlo-based all-hazard risk assessment process

System Performance Metrics
- **Energy Not Served** (ENS) (single scenario) [GWh/y] [4]
- **Expected Energy Not Served** (EENS) [GWh/y] [1]
- Loss of Load Expectation (LOLE) [h/y] [1]

Risk Analysis

- Compute **ENS** using contingency-constrained DC-OPF
- Compute **EENS** by aggregating ENS per initiating event
- Consider component **restoration times** to describe the complete recovery of the system (**resilience assessment**)
- **Ranking of scenarios** and initiating events by their contribution to the global risk
- Ranking of assets/asset classes possible



Outlook

- Results can be used to inform a risk treatment phase
- Application to DESYS grid model of NW Germany

[1] Regulation (EU) 2019/941 of the European Parliament and of the Council of 5 June 2019 on risk-preparedness in the electricity sector and repealing Directive 2005/89/EC.
[2] Veeramany et al., Framework for modeling high-impact, low-frequency power grid events to support risk-informed decisions, Int. Jour. of Disaster Risk Reduction 18, 125-137 (2016); Veeramany et al., Trial implementation of a multihazard risk assessment framework for high-impact low-frequency power grid events, IEEE Systems Journal, 12.4, 3807-3815 (2017).
[3] Moreno et al., From Reliability to Resilience: Planning the Grid Against the Extremes, IEEE Power and Energy Magazine 18 (4), 41-53 (2020).
[4] Espinoza et al., Risk and Resilience Assessment With Component Criticality Ranking of Electric Power Systems Subject to Earthquakes, IEEE Systems Journal 14 (2), 2837-2848 (2020).
[5] Ciapessoni et al., Probabilistic Risk-Based Security Assessment of Power Systems Considering Incumbent Threats and Uncertainties, IEEE Transactions on Smart Grid 7 (6), 2890-2903 (2016).
[6] RTS-GMLC grid model in PowerFactory format, https://github.com/GridMod/RTS-GMLC/tree/master/RTS_Data/FormattedData/PowerFactory, accessed November 1, 2024.

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