Simulating rare interruption events in reliability of supply analysis

Challenge and objective

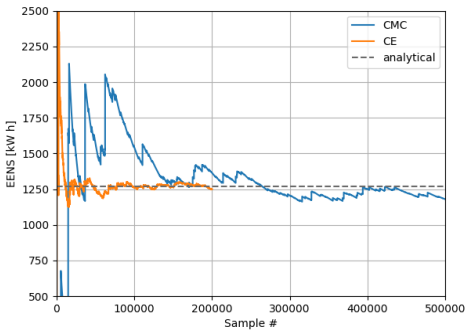
- Power interruptions due to wear-out failures of transformers are relatively rare.
- Assessing the risk of rare, overlapping events in MCS is computationally challenging since capturing these events requires many time-consuming simulations
- Monte Carlo simulation (MCS) is the natural tool to capture more complex behaviours in reliability of supply analysis, compared to analytical methods based on complicated Markov Models
- Modelling of component degradation and wear-out failures in reliability of supply analysis is of particular interest in our case

What have we learned?

- The computational cost of reliability assessment with MCS can be reduced by applying different Variance reduction (VR) techniques, such as
  - Importance sampling using the Cross Entropy method (CE) [1]
  - Conditional / Semi Analytical Monte Carlo (SAMC) conditional on a rare event occurring [2]
- The techniques have in common that they exploit prior knowledge of the system to obtain the same level of accuracy with fewer simulations
- Both methods achieved substantially lower run time when estimating EENS on test systems
- We found that the CE method encounter challenges on large power systems with many components
- The SAMC method requires thought into how historical behaviour of components (before the event occurring) is modelled

Implications and recommendations

- The developed rare event MCS methods can be used to give significant improvements in the run time of reliability assessments, especially when considering rare events
- The CE method that was developed is most useful when analysing smaller systems or sections of a large system
- The SAMC method is scalable to larger grids
- Efficient code is important in all reliability analysis whether VR techniques are applied or not, and is also highly dependent on the power system optimization solver
- Further development and testing of the methods can be useful for activities post-VulPro



Comparison of CE-method convergence for reliability evaluation with (orange) and without (blue) variance reduction [1]

TABLE I
COMPARISON OF PERFORMANCE: SMC AND SAMC PROCEDURES [a]

Method	Iterations	Realizations of contingencies			Computation time (seconds)
		Line 2, Line 3	Line 2, Line 4	Line 3, Line 4	
SMC	10 000	359	385	486	4.163
SAMC	10 000	10 000	10 000	10 000	0.256

[a] Python implementations using Numba [29]. CPU parallel processing of algorithm iterations. Computation time includes summation and parsing of results.

Comparison of simulation iterations, realizations of “rare” contingencies, and computation times, when using traditional MCS (SMC in the table), and the SAMC method developed in [2].

[1] I. Bjerkebæk and H. Toftaker, “Reliability assessment combining importance resampling and the cross entropy method,” *Electric Power Systems Research*, vol. 234, p. 110722, Sep. 2024, doi: 10.1016/j.epsr.2024.110722.

[2] E. S. Kiel and G. H. Kjølle, “A Monte Carlo sampling procedure for rare events applied to power system reliability analysis,” in *ISGT EUROPE 2023 Proceedings*, Oct. 2023, pp. 1–5. doi: 10.1109/ISGTEUROPE56780.2023.10407144.