A rare-event approach to build security analysis tools when $N - k$ ($k > 1$) analyses are needed (as they are in large scale power systems)

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1. Motivation for $N - k$ analyses

Does the $N - 1$ criterion scale to large interconnected networks?

➢ it was originally designed for small to middle size systems;

➢ in large interconnected networks, it is very likely that more than a single power element will be out of use at a specific instant.

⇒ More complex studies ($N - 2$, $N - 3$, ...) have to be performed.
$N - k$ ($k > 1$) studies are combinatorial problems.

⇒ Analyzing individually all possible $N - k$ contingencies is intractable.

Example for a 1000 line electric network:

<table>
<thead>
<tr>
<th>Type of analysis performed</th>
<th>Number of possible contingencies (loss of lines only)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N - 2$</td>
<td>$10^6$</td>
</tr>
<tr>
<td>$N - 3$</td>
<td>$10^9$</td>
</tr>
<tr>
<td>$N - 4$</td>
<td>$10^{12}$</td>
</tr>
</tbody>
</table>
3. Rarity assumption and formulation of the problem

While the set of possible $N - k$ contingencies is extremely large, we assume that the dangerous contingencies are rare.

➢ the problem of performing $N - k$ security studies can be formulated as a problem of identification of rare-events in combinatorial search spaces.

➢ we suggest to use importance sampling techniques to solve it.
4. Proposed procedure

An iterative sampling framework to identify dangerous $N - k$ contingencies: illustration

*Contingency space and contingency to identify*
4. Proposed procedure

An iterative sampling framework to identify dangerous $N - k$ contingencies: illustration

Profile of the severity function
An iterative sampling framework to identify dangerous $N - k$ contingencies: illustration

First sample
4. Proposed procedure

An iterative sampling framework to identify dangerous $N - k$ contingencies: illustration

Evaluation of the severity function
4. Proposed procedure

An iterative sampling framework to identify dangerous $N - k$ contingencies: illustration

*Selection of the best elements*
4. Proposed procedure

An iterative sampling framework to identify dangerous $N - k$ contingencies: illustration

Second iteration: generation of a new sample
4. Proposed procedure

An iterative sampling framework to identify dangerous $N - k$ contingencies: illustration

Final sample
4. Proposed procedure

Technical aspects

➢ *definition of the severity function:*

It should reflect how close a contingency drives the system to its stability limit.

➢ *metrization of the contingency space:*

A metric has to be defined on the contingency space in order to represent contingencies as points in a low-dimensional space.
4. Proposed procedure

Technical aspects: metrization of the contingency space

*Plot of the geographical map of the system (here: IEEE 14 bus system)*
4. Proposed procedure

Technical aspects: metrization of the contingency space

Associating a contingency to each point of the space
4. Proposed procedure

Technical aspects: metrization of the contingency space

Associating a contingency to each point of the space
4. Proposed procedure

Technical aspects: metrization of the contingency space

➢ contingencies corresponding to points that are close to each other in the metrized space are expected to have similar effects on the security of the system.

➢ the geographical representation of the network does not reflect accurately the reality of the system.

⇒ Representing the nodes according to their electrical distance is more relevant.
5. Results on the IEEE 118 bus test system for $N-3$ security analysis

Description of the problem

➢ IEEE 118 bus test system:

➢ $N-3$ security analysis, only line trippings considered.

➢ rate of dangerous contingencies: $2.1 \times 10^{-4}$

⇒ The rarity assumption is relevant.
5. Results on the IEEE 118 bus test system for $N-3$ security analysis

Speed at which one single contingency is identified

![Histogram showing the frequency of iterations for iterative and Monte-Carlo sampling methods](image)
6. Conclusion

We have proposed a framework for efficiently performing $N - k$ security analyses without analyzing individually all the possible contingencies.

Prospects of extension of this framework:

- identification of potentially dangerous generation patterns, topic that gains in importance with the increasing penetration of renewable energies.