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# Searching for Plausible N-k Contingencies Endangering Voltage Stability

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# Background

## Ensuring stability and security

Today's power system analysis increase in **size and complexity**

- globalization of electricity market
  ⇒ **stronger interactions** between individual power systems,
- distributed generation utilizing fluctuating energy sources and
- delays in the reinforcement of the grid, due to e.g. public objection
  ⇒ power system more frequently operated **close to its stability and security limits**.

Under these conditions, **increasing probability** of triggering cascading events leading to **severely deteriorated system conditions or even blackouts**.

⇒ System protection designers need to develop **System (Integrity) Protection Schemes (SIPS)** against these rare, but much impacting events.

Identification of **plausible harmful $N - k$ contingencies** is crucial.

# Searching for plausible harmful N-k contingencies

## Contribution

New method to identify **plausible and harmful $N-k$ contingency sequences**

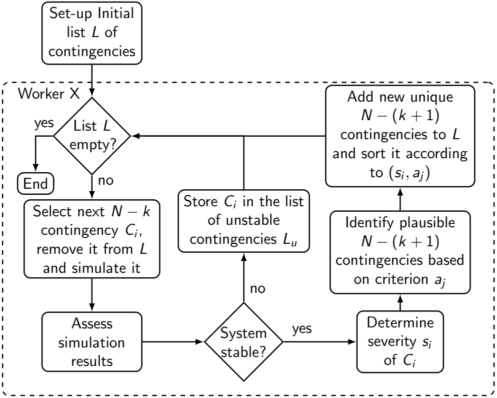
- contingency sequences developed from list of initial contingencies and affected components
- aim is not to identify all harmful $N-k$ contingencies, but rather **all plausible harmful contingency sequences**
- contingency sequences investigated using **time-domain simulations**

Plausible $N-k$ contingency:

- identification of harmful sequences with **small value of $k$**
- candidate contingencies involve **equipment impacted by the sequence**
- **hidden failures** are taken into account

# Searching for plausible harmful N-k contingencies

## Detailed block diagram




- For voltage instability - Severity $s_i$ of $C_i$:

$$s_i = \frac{1}{k_i} \sum_{b \in B} [\max(0, V_b(t_0) - V_b(t_e))]^2$$

- Plausible candidate $k+1$-th contingencies, where $a_j > a_{th}$

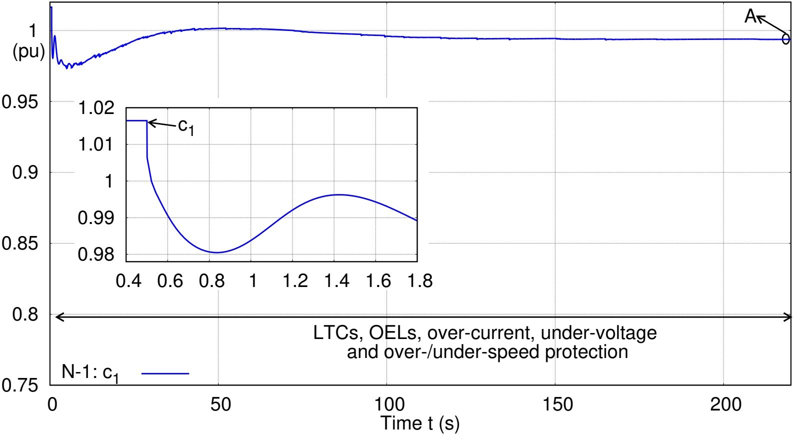
$$a_j = \begin{cases} \alpha \cdot \Delta Q_j, & \forall j \in \text{ generators} \\ \Delta S_j, & \forall j \in \text{ trans. lines} \end{cases}$$

- Unique $N-(k+1)$:
  - no duplicate of a previously simulated contingency in $L$
  - no subset caused instability

# Searching for plausible harmful N-k contingencies

## Illustrative example

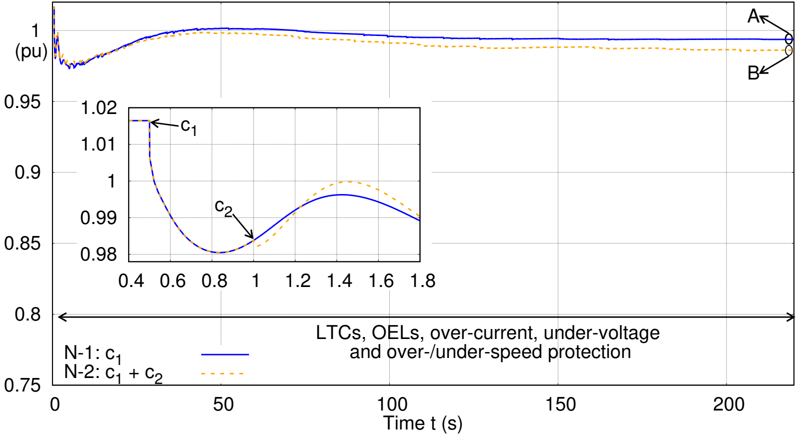
Simulate one $N-1$ contingency from list of initial contingencies and assess simulation results (severity, candidate 2nd contingencies)



# Searching for plausible harmful N-k contingencies

## Illustrative example

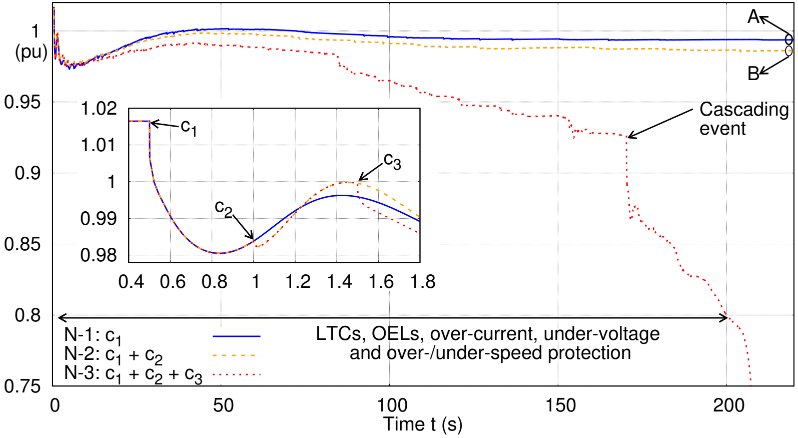
Simulate subsequent $N-2$ contingency and assess simulation results (severity, candidate 3rd contingencies)



# Searching for plausible harmful N-k contingencies

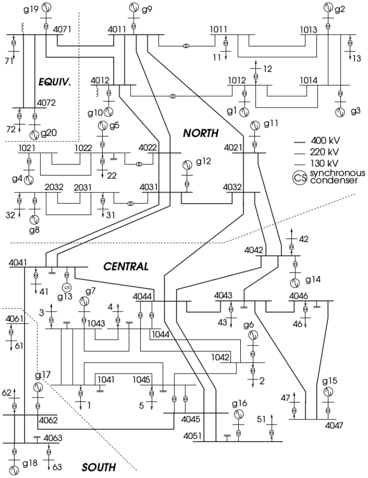
## Illustrative example

Simulate subsequent $N-3$ contingency and assess simulation results



# Simulation results

## Test System & Scenarios




IEEE Nordic Test System

- set up by the IEEE Task Force on "Test Systems for Voltage Stability and Security Assessment"
- all MV loads served through distribution transformers equipped with LTCs
- generators protected with under-voltage as well as under- and over-speed protection

Operating point:

- $N-1$ secure

# Simulation results: performance compared to BF approach

Table: Comparison of number of investigated cases in the Brute-Force (BF) approach and the proposed approach ($N-k$ search).

| Approach | $a_{th}$ | Number of sim. | $N-1$ | $N-2$ | $N-3$ |
|---|---|---|---|---|---|
| BF | – | 55 736 | 74 | 24 514 | 31 147 |
| $N-k$ search | 0.25 | 7 980 | 74 | 812 | 7 093 |
| | 0.50 | 4 364 | 74 | 586 | 3 698 |
| | 1.00 | 1 935 | 74 | 370 | 1 490 |

Table: Comparison of number of identified unstable cases in the BF and the proposed approaches.

| Approach | $a_{th}$ | Number unstable cases | $N-1$ | $N-2$ | $N-3$ |
|---|---|---|---|---|---|
| BF | – | 2 292 | 0 | 226 | 2 065 |
| $N-k$ search | 0.25 | 1 595 | 0 | 222 | 1 372 |
| | 0.50 | 1 196 | 0 | 207 | 988 |
| | 1.00 | 790 | 0 | 176 | 604 |

# Simulation results

## Performance compared to BF approach

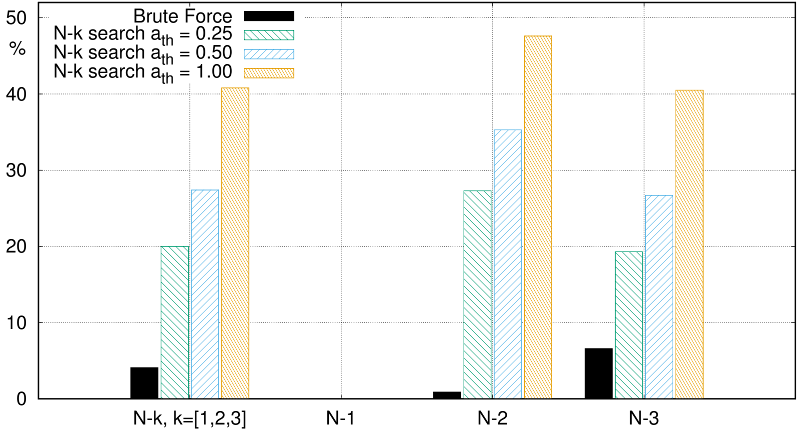



Figure: Comparison of BF and $N-k$ search approaches with respect to probabilities of identifying an unstable contingency when simulating a $N-k$ case, $k=1,2,3$.

# Earliness of identification of harmful contingencies

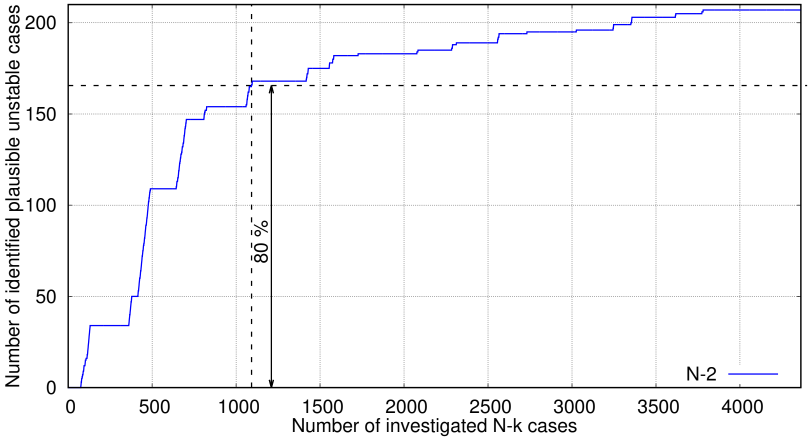



Figure: Number of identified plausible unstable $N-2$ cases vs. number of investigated $N-k$ cases.

# Conclusion

- New approach for **identifying plausible harmful $N-k$ contingencies** based on **detailed time-domain simulations**
- Aim is not to identify all harmful contingencies, but **plausible** harmful contingencies
- Simulation results of a stable $N-k$ case are assessed to determine:
  - severity of $N-k$ contingency (here with respect to voltage stability)
  - plausible $k+1$-th contingency candidates by identifying **components significantly affected**
  - severity index $s_i$ and index $a_j$ ensure that **most severe contingencies are investigated first**
- Tested on IEEE Nordic Test System and performance compared to BF approach
  - number of performed simulations **only a fraction**
  - probability of identifying an unstable case, when assuming limited computational resources, **significantly higher**