2017 IEEE PES Innovative Smart Grid Technologies (ISGT), Europe

Searching for Plausible N-k Contingencies Endangering Voltage Stability

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September 27, 2017

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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**

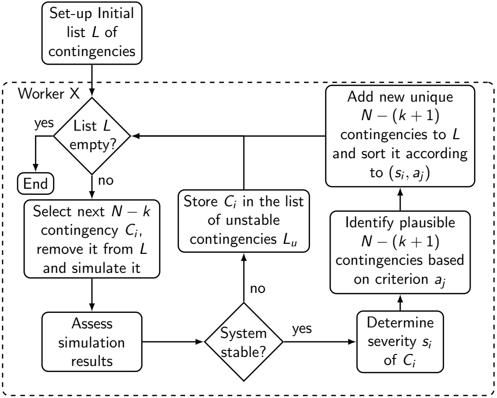
- contingency sequences developed from list of initial contingencies and affected components
- aim is not to identify all harmful $N - k$ contingencies, but rather **all plausible harmful contingency sequences**
- contingency sequences investigated using **time-domain simulations**

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

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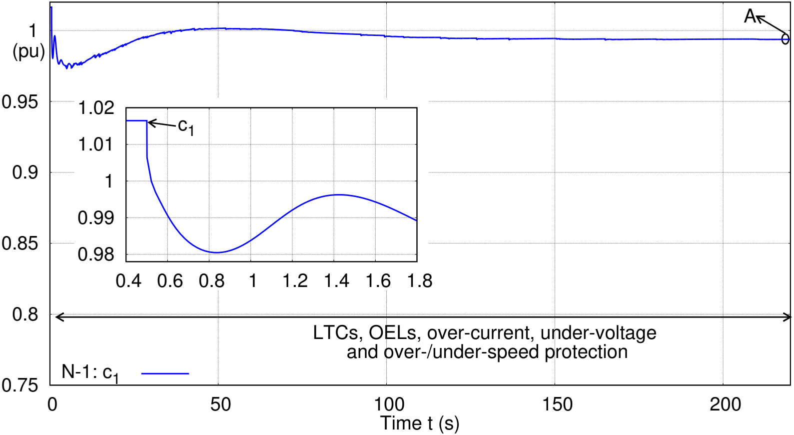
Illustrative example

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



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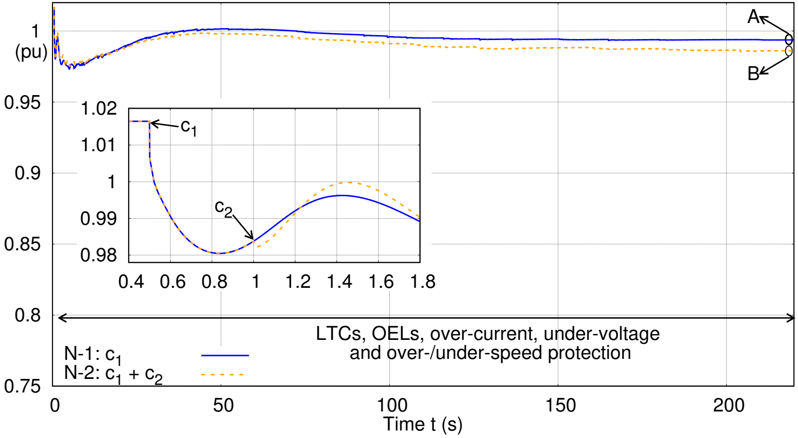
Illustrative example

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



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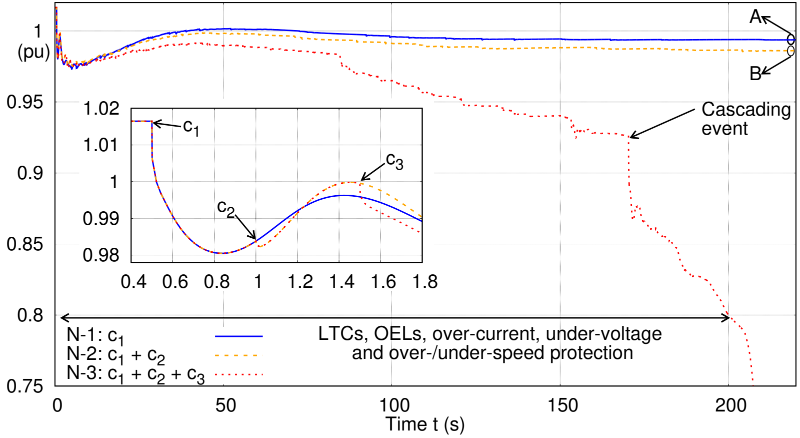
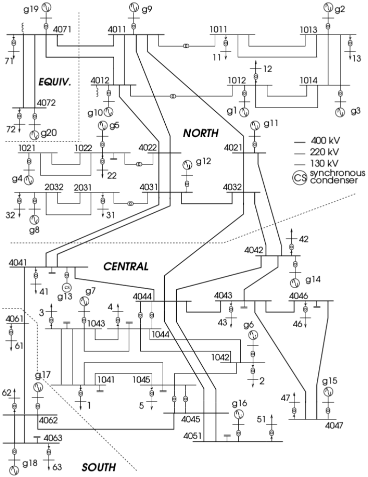
Illustrative example

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

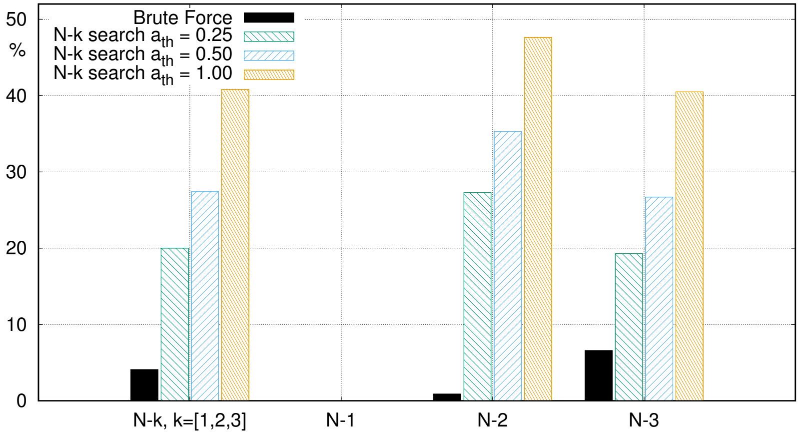


Figure: Comparison of BF and $N-k$ search approaches with respect to probabilities of identifying an unstable contingency when simulating a $N-k$ case, $k=1,2,3$.

Earliness of identification of harmful contingencies

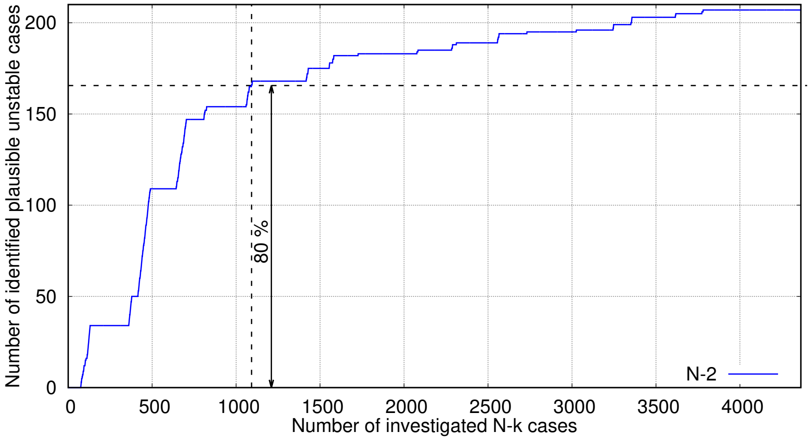


Figure: Number of identified plausible unstable $N-2$ cases vs. number of investigated $N-k$ cases.

Conclusion

- New approach for **identifying plausible harmful $N - k$ contingencies** based on **detailed time-domain simulations**
- Aim is not to identify <u>all</u> 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**