Power System Reliability Assessment Considering the Automatic Definition of Topological Corrective Actions

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Introduction

- Power system operators are required to provide continuous supply of electric power while maintaining strict operating and reliability standards in the most economically efficient possible manner.
- Topological actions:
  - address post-contingency conditions at no additional cost.
  - may not relieve all violations under stressed system conditions
- Individual calculation functions do not relate contingencies to system impacts:

Contingency Analysis | Sensitivity Analysis | Unit Commitment

Proposed Approach

Inputs
- Operation scenarios
- Critical contingencies

Topological corrective actions
To minimize the additional operating expenses (OPEX) following contingencies in the network.

Probabilistic reliability assessment
To quantify the system reliability by associating probabilities to system impacts.

Outputs
Rankings of the most critical contingencies and scenarios

Automatic definition of topological corrective actions (TCA)

PROBLEM: Contingency that leads to an unacceptable operating condition on a given system operating state

SOLUTION: Automatically find the sequence of TCAs that minimize the total cost of the MW change required to restore the system to a new acceptable operating point.

MW change:

- Redispatch of conventional generation
- Curtailment of VRE generation
- Load shedding

TCAs: switching on/off one or more elements

- Automatic definition of single branch outages
- User-defined switching actions

Implementation

A Python command was developed to automate the calculations using built-in PowerFactory functions.

MASTER LOOP

Sequentially iterates over each critical contingency to be analysed

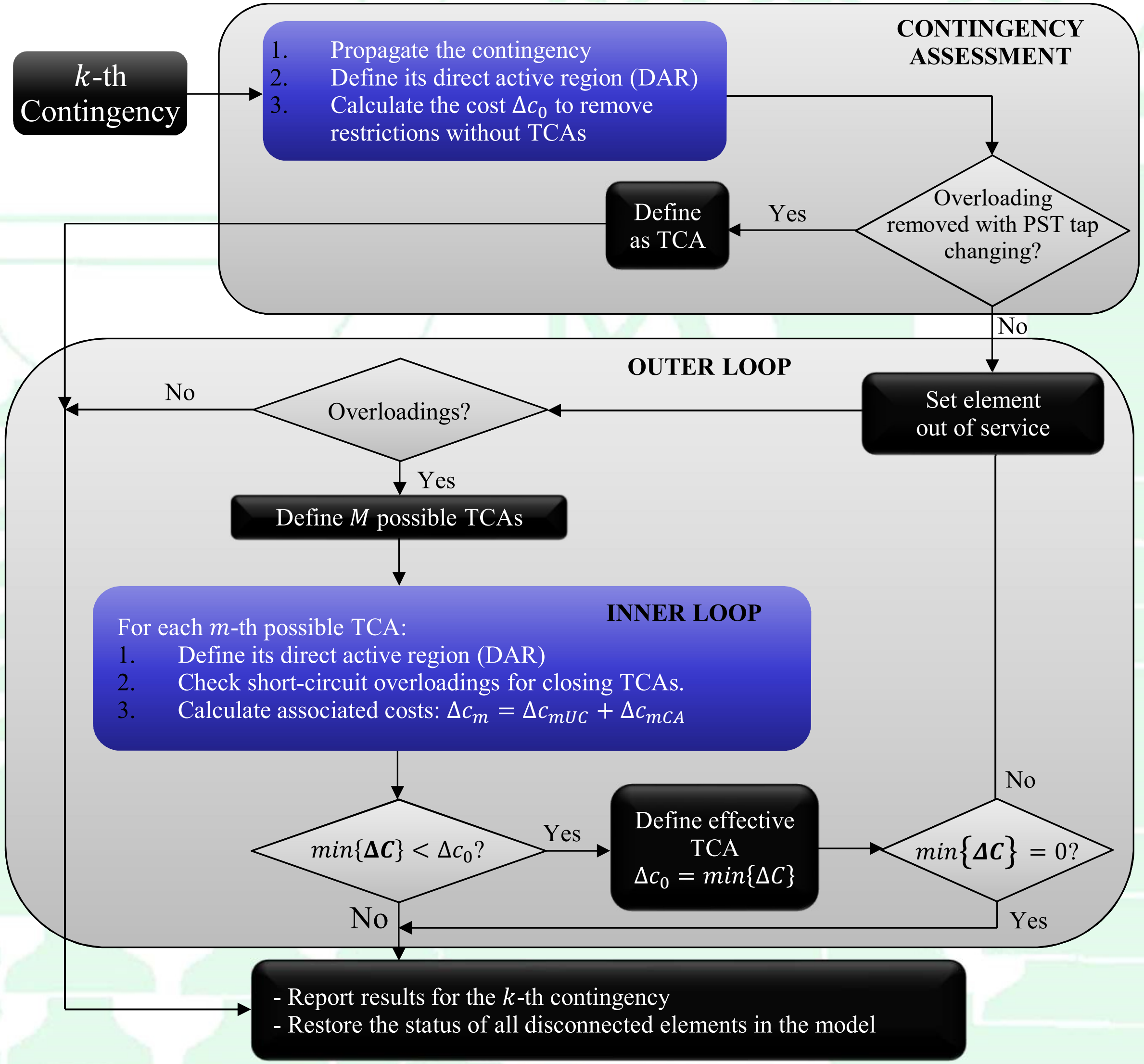
OUTER LOOP

- Iterates over the network states after applying an effective TCA.
- A “possible” TCA is considered an “effective” TCA if it allows to reduce the costs of MW change with respect to the state in which it is not applied.

INNER LOOP

Iterates over the set of possible TCAs for each network state and determines their effectiveness to reduce the post-contingency OPEX.

Master loop iteration



TCA: topological corrective action; PST: Phase-shifter transformer

Total costs of MW change

$$\Delta c_m = \Delta c_{mCA} + \Delta c_{mUC}$$

Outage impact

- Outages are propagated by disconnecting the elements with loadings above the maximum allowed value L_{maxST}.
- The MW load and generation disconnected by the TCA are affected by fixed costs in $/MW.

Economic optimization

- Run only for TCAs that do not lead to uncontrolled cascade tripping or short-circuit overloadings.
- A UC redispatch calculation is run to obtain the total cost of the required MW change.

Probabilistic Reliability Assessment (PRA)

- **Contingency reliability cost**

  Measures the reliability of contingency *k*:

$$CRC_k = p_k \times \Delta c_k \times d_k,$$

  where
  - p_k is the probability of occurrence of the *k*-th contingency,
  - Δc_k the cost of the MW shift required to eliminate the overloadings,
  - d_k the contingency duration.

- **Scenario reliability cost**

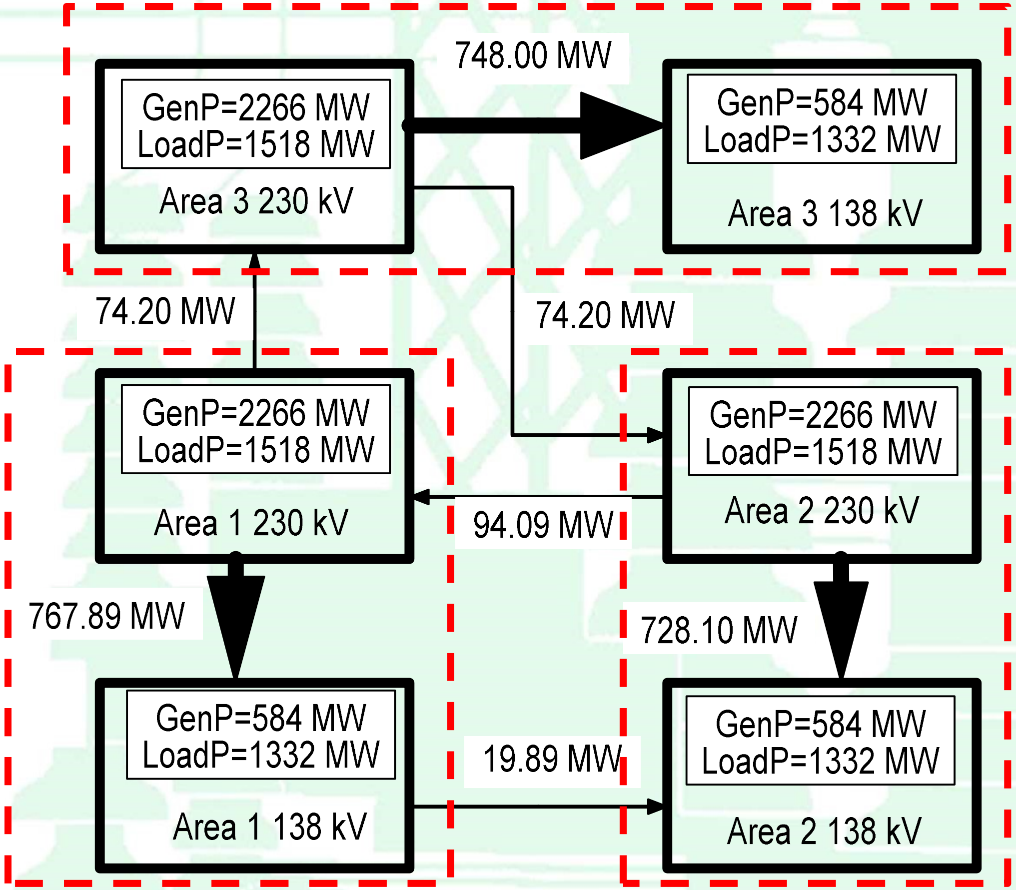
  Measures the reliability of scenario *s:*

$$SRC_s = \sum_{k=1}^{K_s} CRC_k,$$

  where K_s is the number of critical contingencies in the *s*-th scenario.

Test system: IEEE RTS-96 three-areas model

- 73 buses, 120 branches and 96 generating units
- Peak load of 8550 MW.
- 120 contingencies (disconnection of a line or a transformer).
- 29 contingencies lead to overloadings and were therefore processed.
- MW shift costs assigned to generators and loads
- Failure rate assigned to branches



Five contingencies with the highest CRC in the base scenario (S1).

Outage			Without TCA			With TCA			CRC Red. (%)	Effective TCAs
k	Element	Prob (1/h)	ΔE (MW)	Δc ($/h)	CRC ($/h)	ΔE (MW)	Δc ($/h)	CRC ($/h)		
16	12_23_1 A3	6.683E-05	244	3053	**0.204**	105	1150	0.077	62	Open 12_13_1 A3, Open 11_9_1 A3
19	13_23_1 A3	5.984E-05	**274**	**3223**	0.193	274	3223	0.193	0.0	None
15	12_23_1 A2	6.683E-05	218	2724	0.182	0	0	0.000	100	Open 12_13_1 A2, Open 11_10_1 A2, Change PST taps
18	13_23_1 A2	5.984E-05	250	2922	0.175	190	2379	0.142	19	Change PST taps
27	15_21_1 A2	3.391E-05	214	2478	0.084	114	1227	0.042	50	Change PST taps

Critical contingencies

- Technical viewpoint: #19 (highest post-contingency MW shift and additional OPEX).
- Reliability viewpoint: #16 (highest CRC without TCAs).

TCA optimization results for contingency #16 in the base case (S1).

- Required TCAs:

Disconnection of

Line 12_13_1 A3

Transformer 11_9_1 A3

-- Change in Generation

#	Generator	MW Change (MW)	MW Change Cost ($/h)
1	01_1 A3	10.0	150.0
2	01_2 A3	3.4	50.8
3	02_1 A3	10.0	150.0
4	02_2 A3	10.0	150.0
5	22_1 A3	-2.7	13.5
6	22_5 A3	-50.0	250.0

Total Generation MW change: 86.08 (+33.39/-52.69) MW at $764.31

-- Change in Load

#	Element	MW Change (MW)	MW Change Cost ($/h)
1	load 14_1 A3	19.3	386.0

-- No transformer tap changes are required

- Overall Total MW change: 105.38 MW, $1150.35

Analysis of additional scenarios

- Additional scenarios S2 and S3: the loads of the 138 kV and 230 kV networks were scaled +/-10%.

Scenario	Load (MW)	SRC ($/h)		SRC Reduction (%)
		Without TCA	With TCA	
S1 (base)	8550	1.650	0.800	51.5
S2	8550	**1.836**	0.841	54.2
S3	9101	1.095	0.462	57.8

- Most critical scenario = S2 (highest SRC without TCAs).
- The effective TCAs allow to reduce the SRC in the three scenarios.

Conclusions

1. Proposed approach implemented using built-in PowerFactory functions.
2. The most critical contingencies for a given scenario can be identified in terms of the highest CRC, and the most critical scenario in terms of the highest SRC.
3. The effective TCAs allow to reduce the CRC in all contingencies and the SRC in all scenarios.
4. The most critical contingency from a reliability viewpoint might not necessarily be the one requiring the highest MW shift to remove overloadings.