Risk Assessment of Switching Measures in Electrical Transmission Systems

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FGH

Motivation

Switching Measures in Transmission System Operation

- Reasons to change switching state by operational management:
  - Maintenance
  - System security (remedial measure)
- Operational constraints for switching: U, I, ΔΘ, ΔU, I''_{k3}

➔ To be checked before implementation

- Usual approach identifying measures in system operation:
  1. Offline determination of white list/maintenance plan (e.g. using topology optimization developed by FGH e.V.)
  2. Online check of operational constraints (from operational planning to real time)
- Random faults in power systems inevitable

➔ Certain endangerments as “side effect” of switching

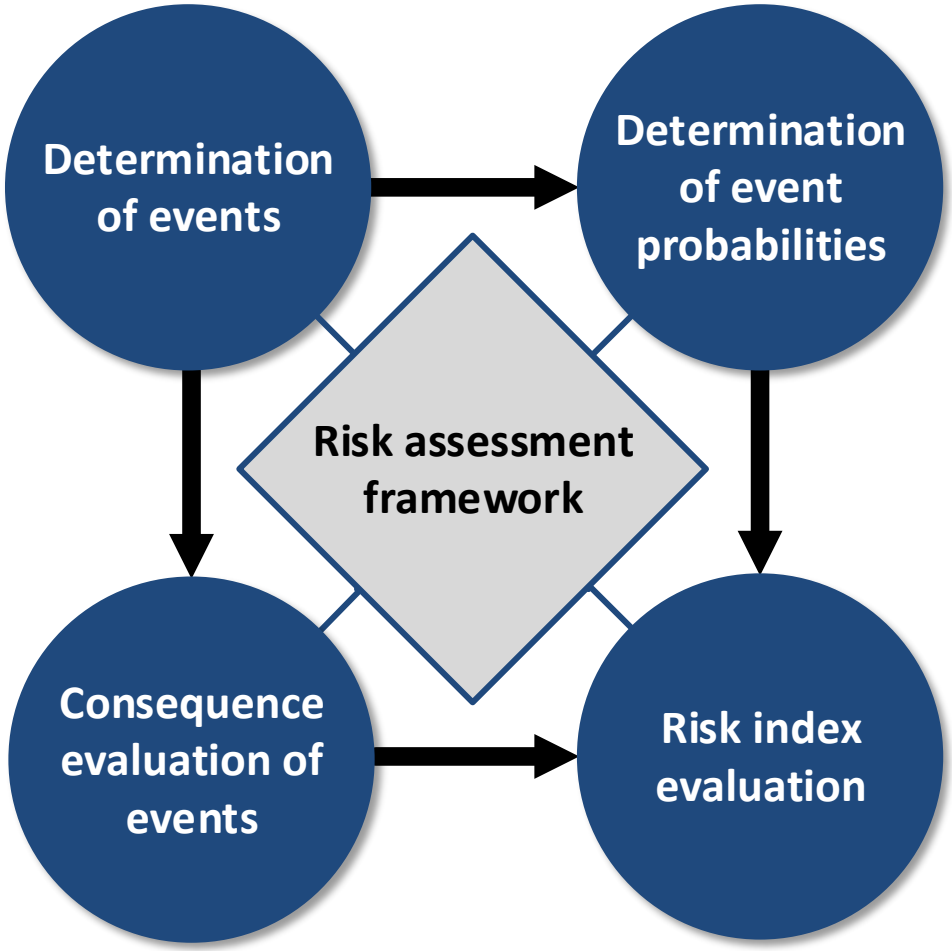
- Quantitative measure for endangerments of switching measures required

➔ Remedy: Risk index of envisaged switching measures

General Procedure of Risk Assessment

Overview

- Required steps towards risk assessment[1]



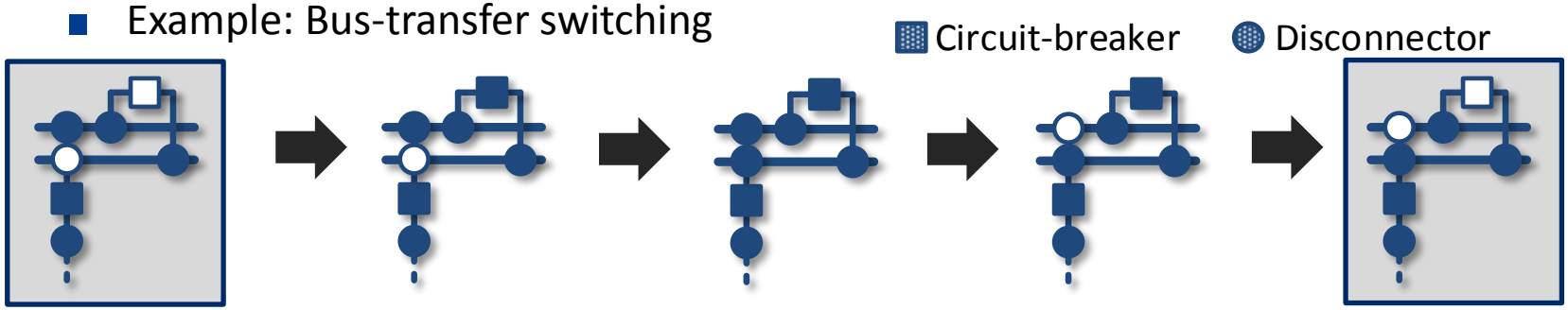
$$Risk = \sum_{Events} P_i(E_i) \cdot Con(E_i)$$

[1] Li, W.: "Risk Assessment of Power Systems – Models, Methods and Applications", 2014

Determination of Events

Risk assessment - Step 1

- Temporary switching states (TSS) occur due to technical constraints
  - Example: Bus-transfer switching



- Endangerments due to switching:
  - Different security level for TSS possible
    (not necessarily N-1 secure, effectiveness of protection limited)
  - Higher failure rate of switchgears used for frequent switching[1]

➔ Definition of relevant events for risk assessment of switching measures:

  - Short-circuit on network elements for a given TSS
  - Short-circuit on network elements **along with** mal-functioning of switchgears for a relevant switching states

➔ Determination as outage situations (protection zone) for further analysis

[1] Janssen, A. et al.: "International Surveys on Circuit-Breaker Reliability Data (...)", 2014

Determination of Event Probabilities

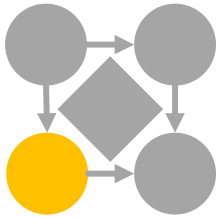
Risk assessment - Step 2

- Limitation to one (independent) short-circuit at a time (i.e. per switching measure)
  - Assumption: Failures of higher order only of negligible probability
  - Focus: Network elements of substations affected by switching measure
- Switchgear reliability
  - Disconnector pure mechanical device (not able to break/make currents)
  - "(…) from point of view of reliability, a circuit-breaker is mainly a mechanical device"[1]
  - ➔ Relevant failures: Stuck of switchgear
  - Focus: All relevant switchgears for implementing considered switching measure
- Probability data
  - Based on historical records (e.g. German FNN Störungs- und Verfügbarkeits-statistik, CIGRE international enquiries on circuit-breaker failures)
  - Use of online monitoring data for CB reliability assessment possible[2]

[1] Smeets, R. et al. „Switching in electrical Transmission and Distribution System", 2015

[2] Natti, S. et al.:„A Risk-Based Decision Approach for Maintenance Scheduling Strategies (…)", 2008

Consequence Evaluation of Events



Risk assessment - Step 3

- Outage situations induced by short-circuit on relevant network element (line, transformer, busbar)
- Impact of switchgear failures:
  - Remaining in temporary switching state
  - Circuit-breaker: Extended protection zone
- Evaluation of resulting outage situations by cascade simulation
  - Overloaded lines cause subsequent component outages
  - ➔ Fast evaluation by use of power injections method
  - Stop of simulation after pre-defined number of component outages
- Definition of consequences for a particular outage situation:
  - Sum of lost transmission capacity [MVA]

➔ Consequence evaluation for a relevant switching state

- Cascade simulation for each relevant event (short-circuit, short-circuit along with CB failure)

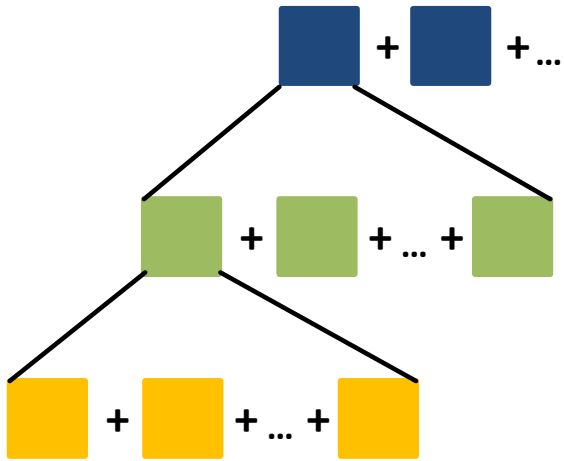
Risk Index Evaluation for Switching Measures

Risk assessment - Step 4

- Definition of switching measure:
  Consists of at least one elementary switching measure
  - Switching on/off transformer or line
  - Changing busbar allocation of network element (bus-transfer)
  - Closing/opening busbar coupler

➔ Calculation of risk of a switching measure:

$$\text{Risk} = \overset{A}{\Sigma}\overset{B}{\Sigma}\overset{C}{\Sigma} P(\text{Situation}) \cdot \text{Con}(\text{Situation})$$



→ Set of elementary switching measures

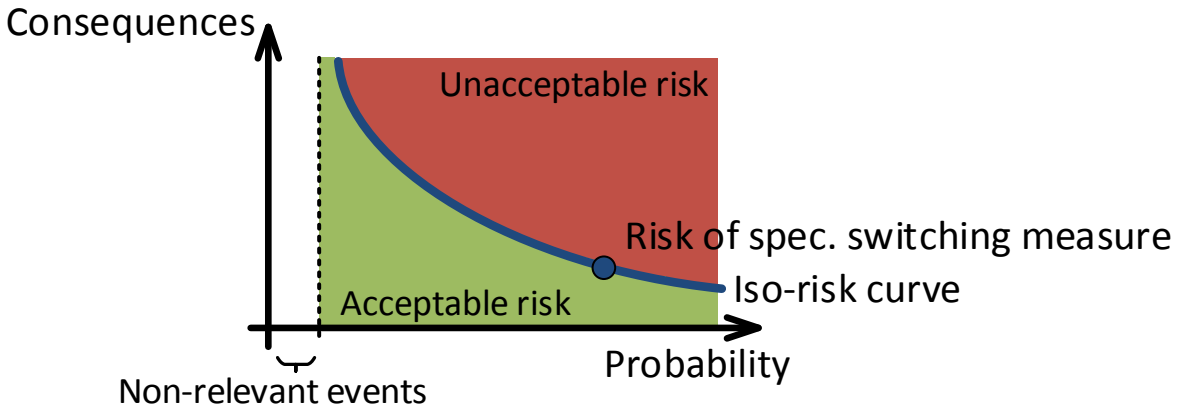
→ Set of (temporary) switching states

→ Set of relevant outage situations

Risk Index of Switching Measures

Towards Application in Operational Management

- Representation of risk graph



➔ Definition of maximum accepted risk required

- Application in real-time operation
  - Continuous risk assessment of “queued” switching measures

➔ Find admissible point in time for implementation

- Application in (offline) topology optimization
  - Admissible risk limit as constraint for OPF

➔ Take operational constraints into account