Numerical techniques for dynamic probabilistic risk assessment of cascading outages

Cascading Failure Working Group of

IEEE PES Computer and Analytical Methods Subcommittee (CAMS)

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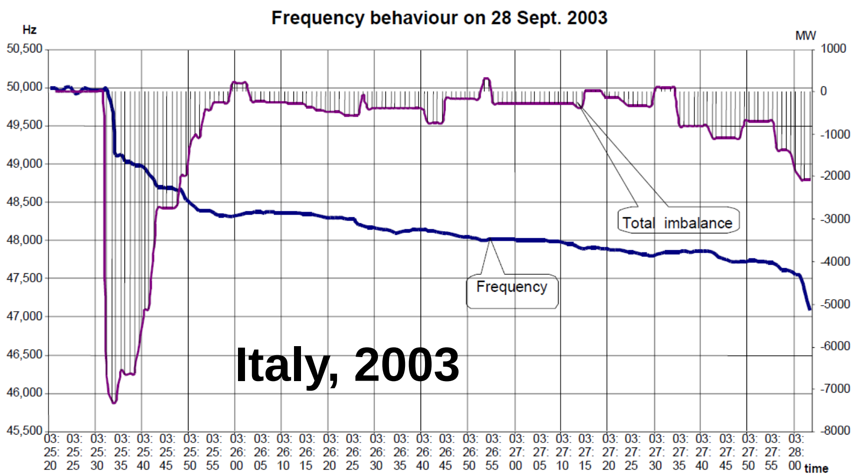
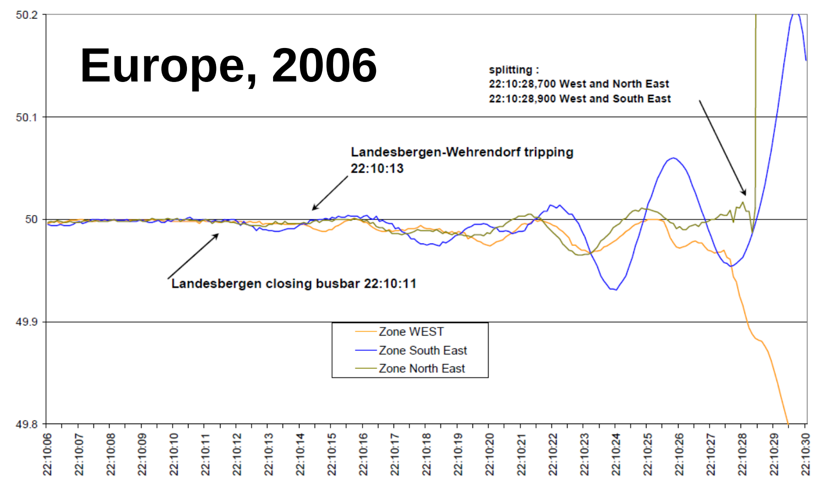
Introduction

- Cascading outages
  - Involve dynamic cascading phenomena (frequency instability, angular instability, voltage collapse, etc.)





  - Underlying cascading mechanism: the electrical transient triggers protection systems of power system (generation/transmission) elements

Introduction

- Protection systems are not perfectly reliable
  - They can fail to disconnect elements when they are supposed to do so (missing trips)
  - They can disconnect elements when they are not supposed to do so (unwanted trips)
  - Erroneous operation of protection systems is a major cause of cascading outage (e.g. 1996 WECC disturbances)

Introduction

- Probabilistic Risk Assessment (PRA) of cascading outages
  - Purpose: estimate the risk=probability×consequences of cascading outage scenarios
  - Consequences of interest: loss of load (load shedding)
- A PRA of cascading outages must consider
  - Dynamic phenomena
  - The stochastic behaviour of protection systems

  → ***Concept of dynamic PRA***

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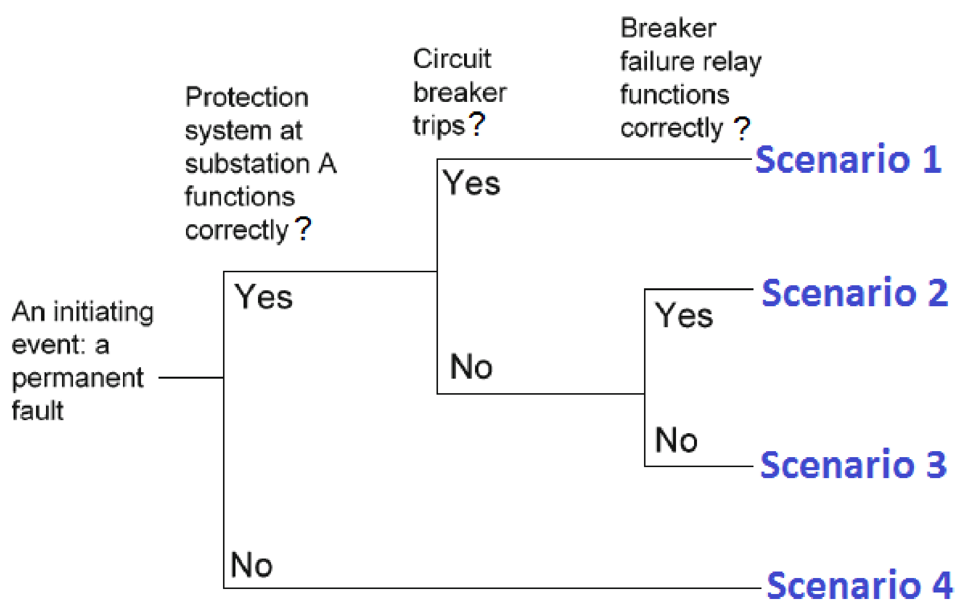
Dynamic PRA of cascading outages

- Purpose
  - Identify cascading outage scenarios
  - Estimate their probabilities (or their frequencies)
  - Estimate the loss of load induced by each of them

Dynamic PRA of cascading outages

- Classical PRA technique: Event Tree
  - Probability of each scenario = product of the probabilities of successive embranchments
  - Dynamic simulation of each branch to estimate consequences (loss of load)



Dynamic PRA of cascading outages

- “Classical” Event Trees irrelevant for dynamic PRA
  - Events are triggered by the power system dynamics: they cannot be predicted beforehand
  - Events can occur at any time (e.g. measurement errors): the number of branches (possible scenarios) is infinite

  → ***Extension of the concept: Dynamic Event Trees (DETs)***
- DETs
  - Coupled analysis of the power system dynamics and events due to the action of protection systems
  - Infinite number of branches → Any numerical technique must find a way to limit the analysis to a finite number…

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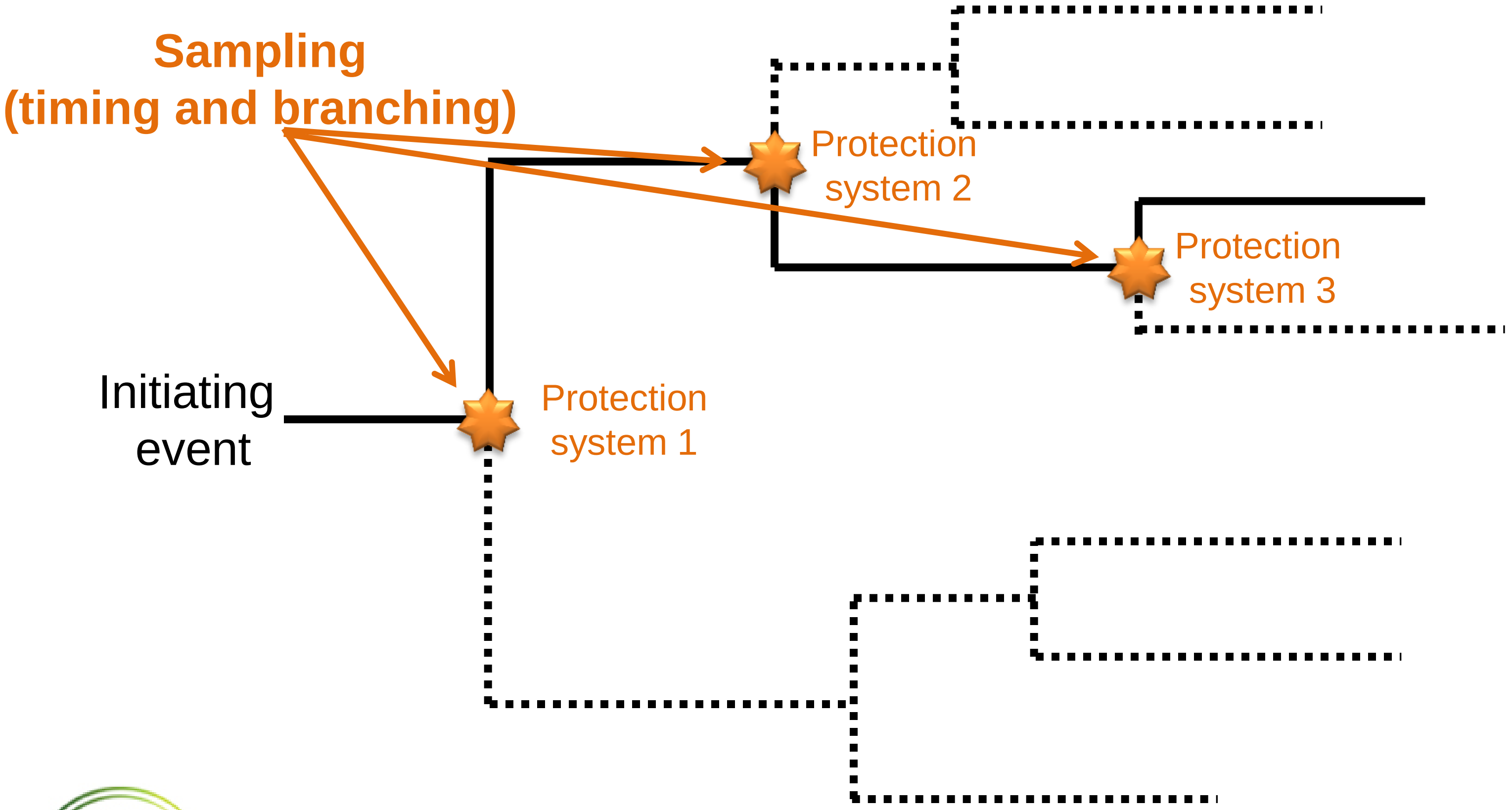
Numerical techniques

- Most naïve way to limit the analysis to a finite number of branches: Monte Carlo (MC) simulation
  - The stochastic behaviour of protection systems is sampled beforehand
  - The branch of the DET corresponding to this behaviour is simulated (deterministic simulation)
  - The process is repeated for a “large” number of runs (until satisfactory statistical accuracy is reached)

Numerical techniques

- Monte Carlo simulation scheme



Numerical techniques

- Problem of MC simulation: poor efficiency
  - Cascading outages are rare events in real (modern) power systems
  - If probability to have a major disturbance after an initiating event (e.g. fault on a line) is 10^{-4}, need of nearly 1 million of dynamic simulations to reach a satisfactory statistical accuracy
  - It will require several weeks of computation for real systems
  - But most (>99%) of the computation time is spent to simulate secure events

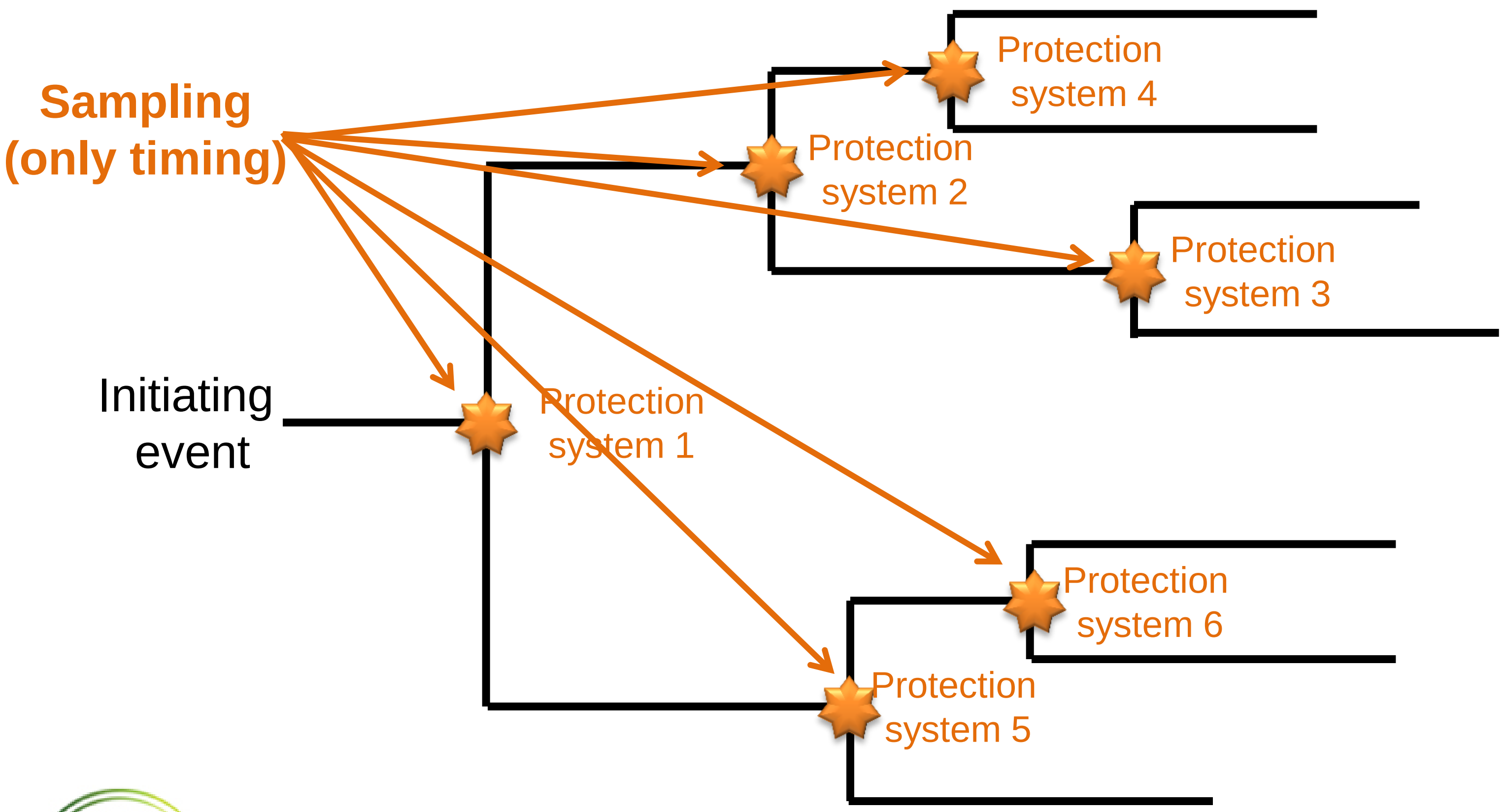
→ ***Need for more efficient numerical techniques***

Numerical techniques

- Alternative #1: MC-DET
  - Sources of stochasticity: continuous (e.g. measurements errors) + discrete (e.g. breaker failures)
  - For a specific set of values of continuous random variables, the DET contains a finite number of branches (discrete failures)
  - MC-DET simulation scheme
    - Continuous random variables are sampled beforehand
    - The DET corresponding to this set of values is fully simulated
    - The process is repeated for a “large” number of runs (until satisfactory statistical accuracy is reached)

Numerical techniques

- MC-DET simulation scheme



Numerical techniques

- Problem of MC-DET: possible combinatorial explosion of branches
  - A real power system contains numerous protection systems (maximum number of branches: 2^N)
  - Some branches are very unlikely to happen (e.g. several circuit breaker failures)
  - The MC-DET will explore these branches, even if the contribution to the total risk is negligible
  - Possible solution: cut-off of branches with a probability lower than a threshold

Numerical techniques

- Alternative #2: DDET
  - Discrete DET: embranchments are restricted in time to discrete time steps (larger than the time steps used in the numerical simulation of the power system dynamics)
  - Cut-off techniques to limit the combinatorial explosion (several new branches at each embranchment point allowed)
- Alternative #3: Skeleton-based Monte Carlo
  - Skeleton: setpoint-based (“average” value of random variables) DET
  - New branches grafted on the DET by MC simulation

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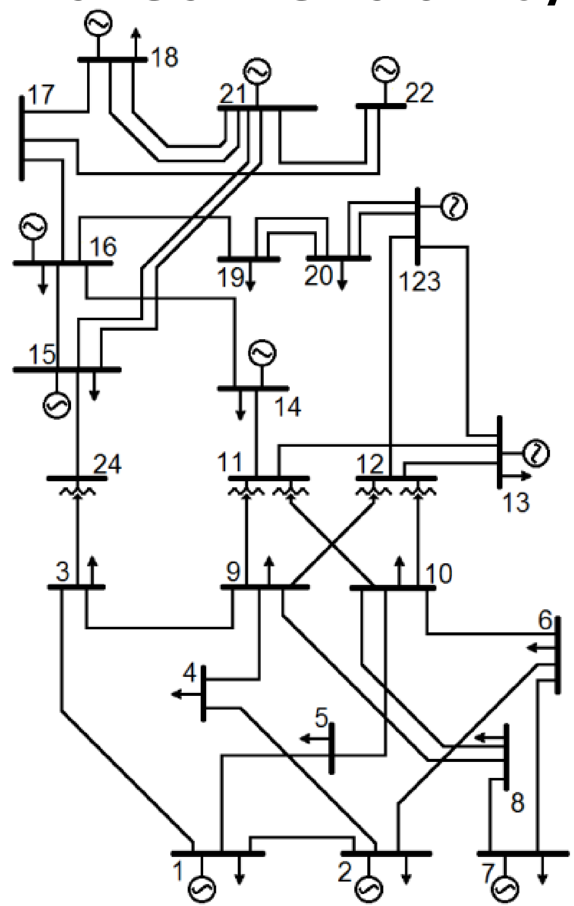
Example

- Test system: 1-area Reliability Test System



Example

- Simplified set of assumptions
  - Stochastic behaviour of distance protection systems only (but representative set of protection systems in the model)
  - Circuit breaker failures and measurement errors
- Figure of merit
  - $Fom = \frac{1}{s^2\bar{t}}$
  - Related to the computation time needed to reach a specified statistical accuracy (inverse)
- Quantity of interest: probability to have a blackout after a fault on a specific line (between buses 1 & 2)

Example

- Main (preliminary) results
  - Measurement errors = 1%
    - Probability to have a blackout=1%

	MC	MC-DET
Time per simulation (s)	4.3	557
Sample variance (-)	0.0126	0.0000326
Figure of merit (s^{-1})	19.5	55.1

  - Measurement errors = 5%
    - Probability to have a blackout=1.2%

	MC	MC-DET
Time per simulation (s)	4.3	600
Sample variance (-)	0.0136	0.0000866
Figure of merit (s^{-1})	17.1	19.2

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Conclusions

- Numerical methods exist for dynamic probabilistic risk assessment, but are not all yet applied to the specific problem of cascading outages
- Analog Monte Carlo simulation is inefficient to track rare events such as cascading outages
- MC-DET can be more efficient than MC, but the gain of a standard application is limited
- MC-DET could be improved to limit the analysis to relevant branches
- Others techniques should be studied