Steady-State Security and Short-Term Power System Reliability Management

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Symposium on Stability Assessment and Intelligent Control for Sustainable Electrical Power Systems

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Objective of the presentation

- To explain
  - Current practice in terms of steady-state security and short-term reliability management in power systems
  - How to move beyond the state-of-the-art reliability management

- Chapter 2: Steady-state security, Heylen Evelyn, De Boeck Steven, Ovaere Marten, Ergun Hakan, Van Hertem Dirk, in *Dynamic vulnerability assessment and intelligent control for sustainable power systems, 2018*

Reliability: general aspects

Reliability: *The ability that an item can perform its* ***required function*** *under* ***given conditions*** *for a* ***given time interval***

Commonly used measures: Mean time between failures, failure rate

- Power system reliability:
  - Adequacy: Existence of sufficient facilities to satisfy consumer load demand
  - **Security**: Ability to respond to disturbances arising within the system

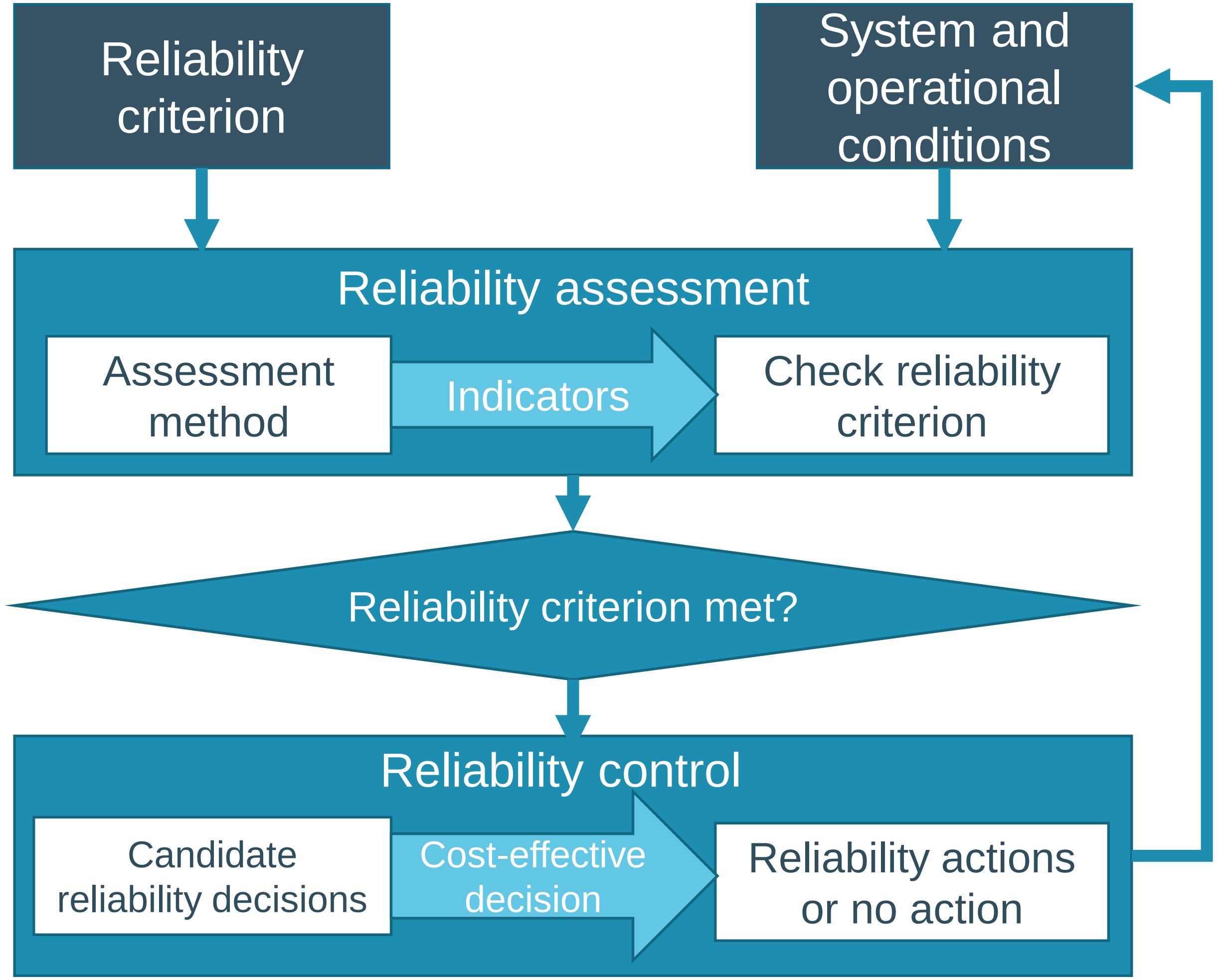
Acceptable power system reliability level
→ Reliability criterion
→ Reliabiltiy management

Outline

- Power system reliability management
  - The N-1 criterion
  - Reliability assessment
  - Reliability control
- Beyond the N-1 criterion
- Conclusions

Power system reliability management

Power system reliability management



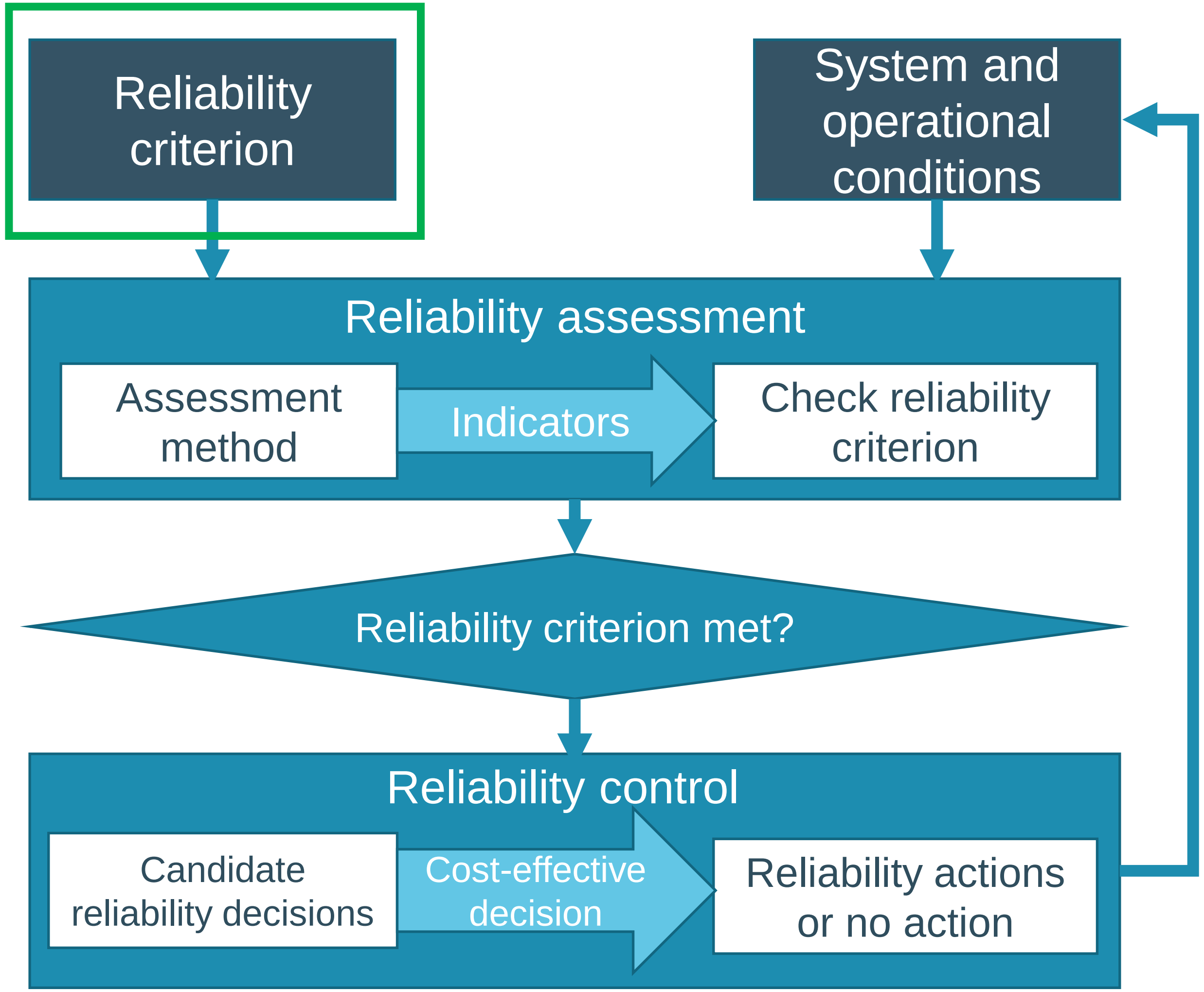
Reliability management approach and criterion

1. Reliability criterion

2. Reliability Assessment

3. Reliability control

The N-1 reliability criterion



Reliability management approach and criterion

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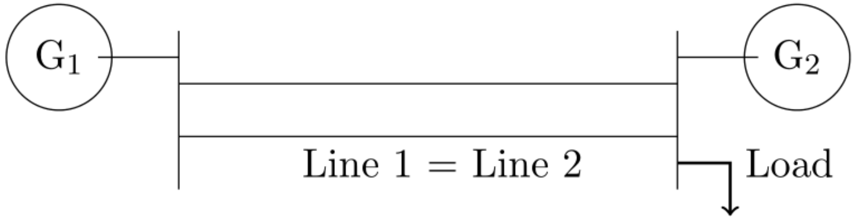
Current security management based on deterministic N-1 criterion

- Definition: *The system should be able to withstand at all times the loss of any of its main elements without significant degradation of service quality*



Shortcomings of the currently used N-1 criterion

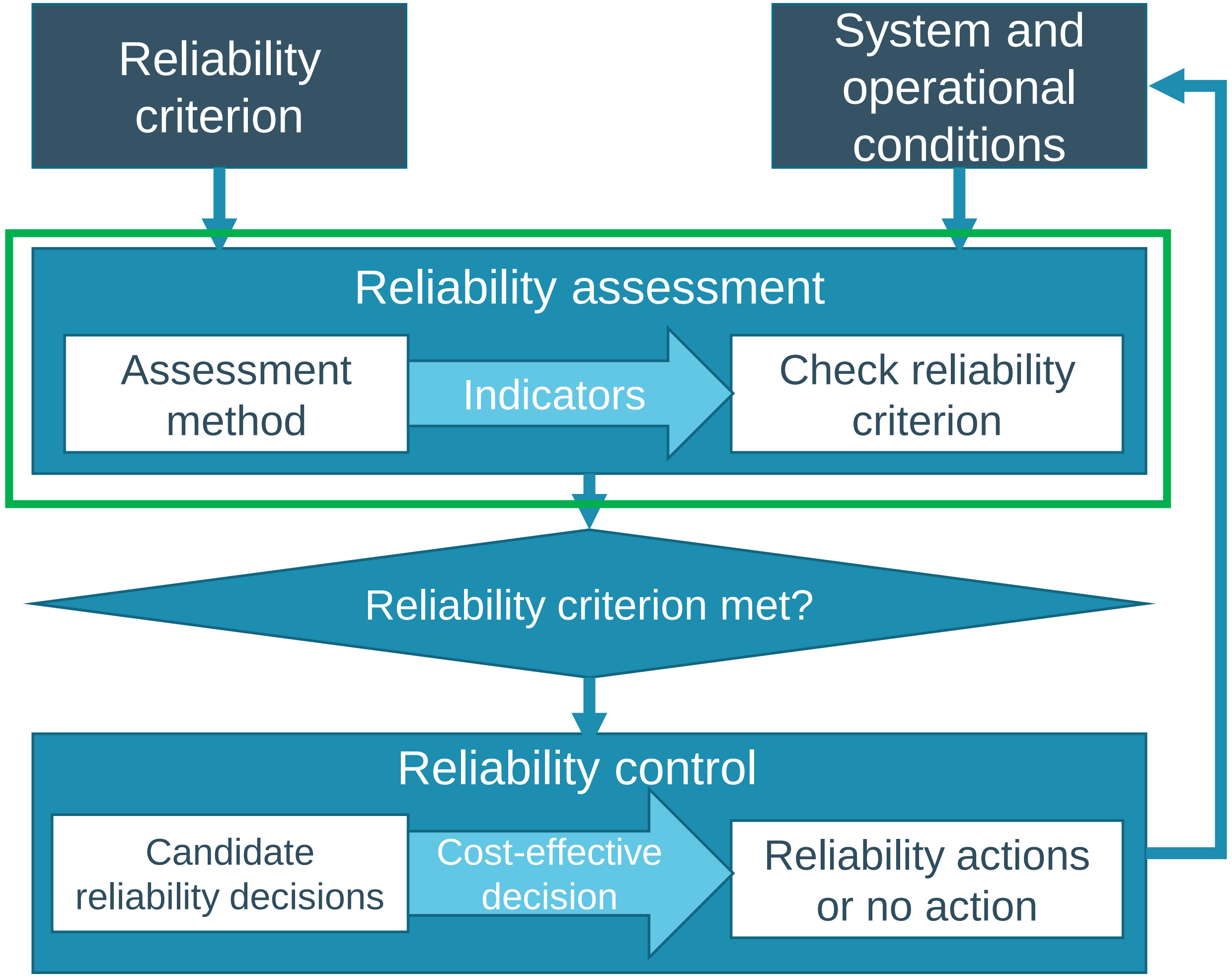
Shortcomings

- Only single contingencies are considered
- Exact probabilities of contingencies not considered
- All credible states equally severe
- All consumers assumed equally important
- Different interpretations by different transmission system operators
- Binary criterion

Evolutions

- Uncertain and variable renewable energy sources
- Modern technologies
- Importance of cost-effectiveness and socio-economic aspects

Reliability assessment



Reliability management approach and criterion

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Security assessment

Determines whether immediate response of the system to a disturbance generates potential reliability problems

Dynamic security assessment

$$\frac{d\mathbf{x}}{dt} = k(\mathbf{x}, \mathbf{y}, \mathbf{a})$$

$$0 = h(\mathbf{x}, \mathbf{y}, \mathbf{a})$$

Transient trajectory

Steady-state security assessment

$$0 = k(\mathbf{x}, \mathbf{y}, \mathbf{a})$$

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Equilibrium states

→ Power flow

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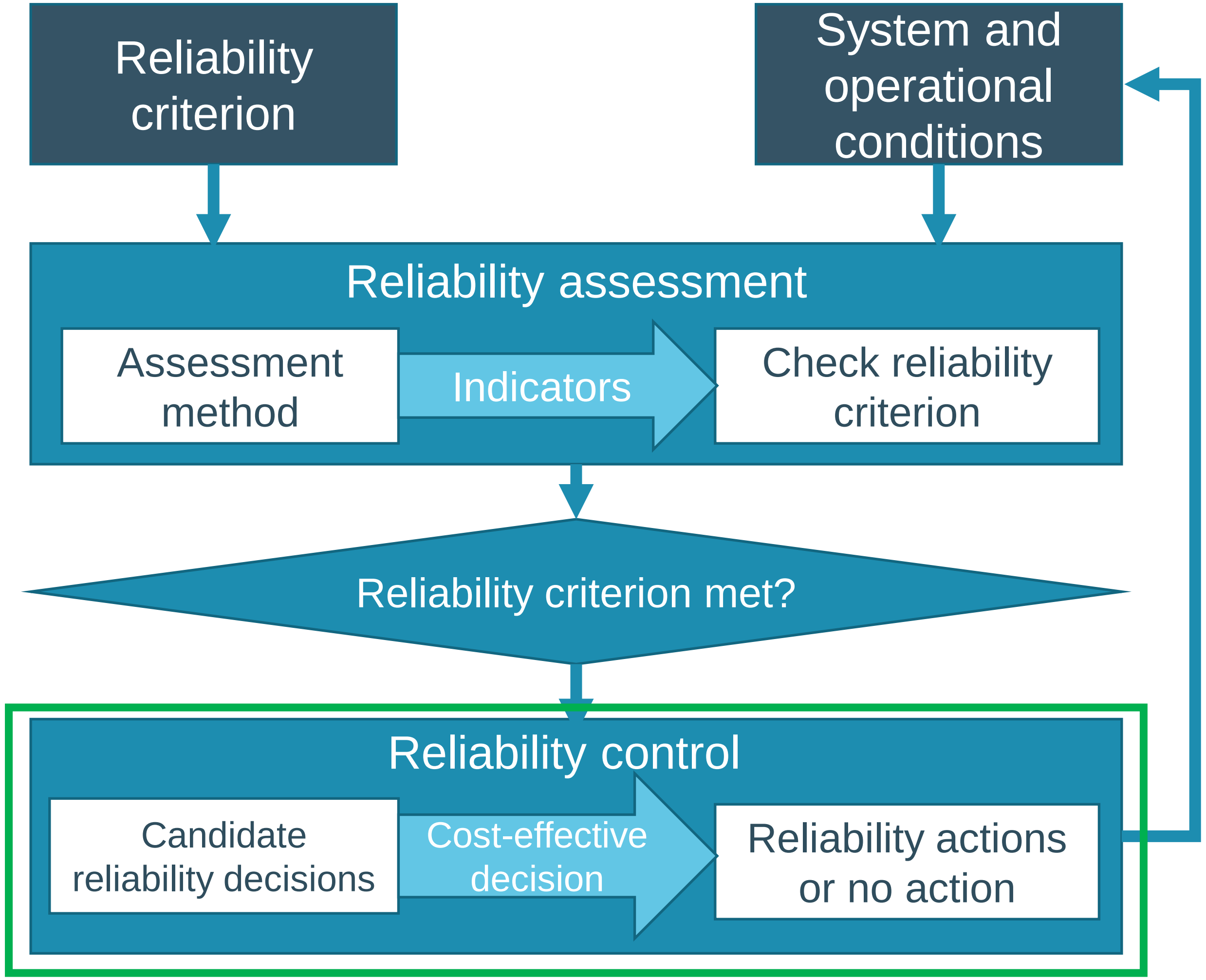
Reliability control



Reliability management approach and criterion

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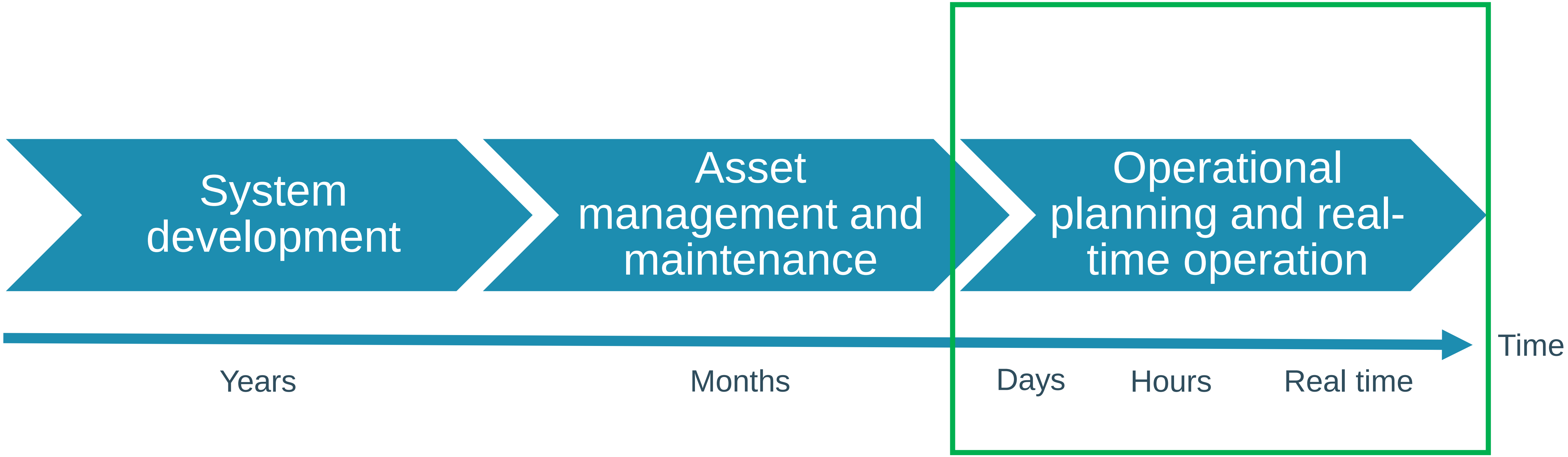
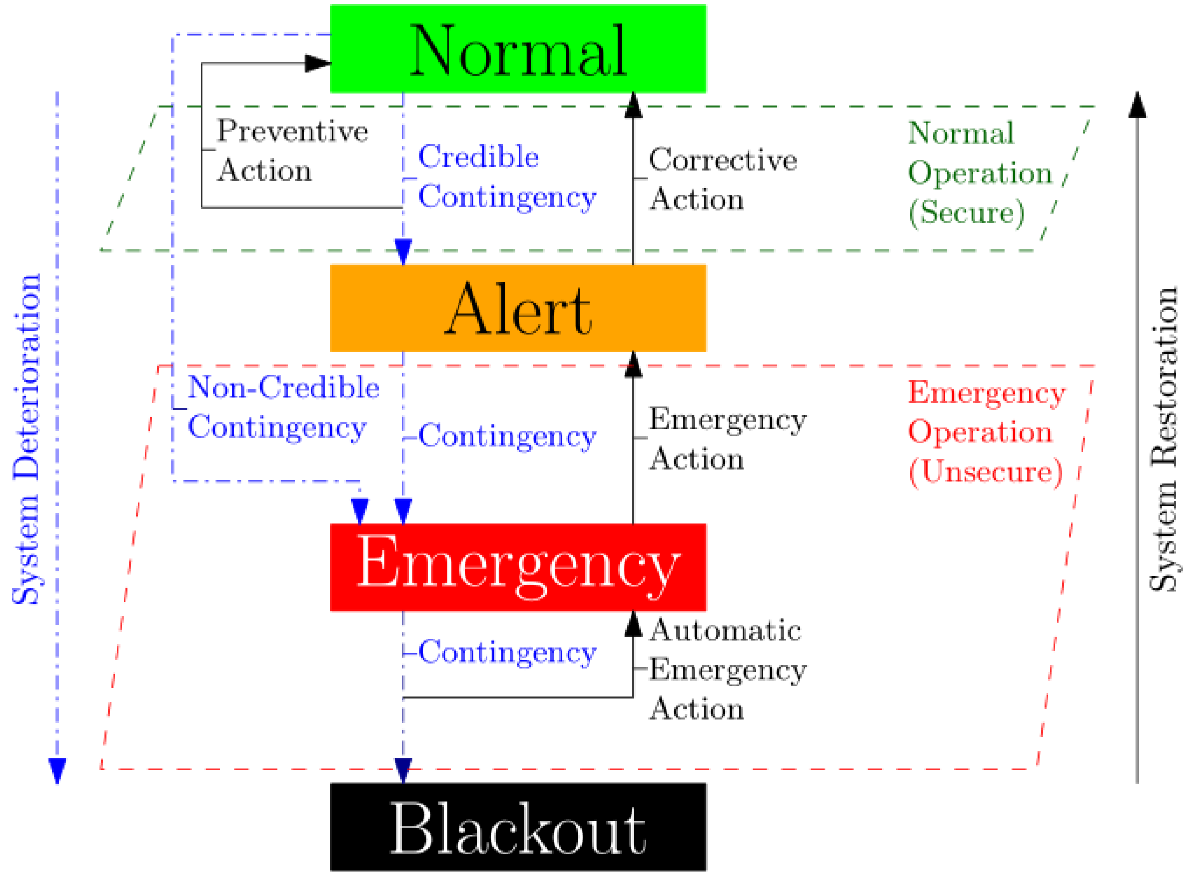
Reliability control decision stages

Reliability control decision stages



Power system operational states in short-term reliability management based on N-1 criterion

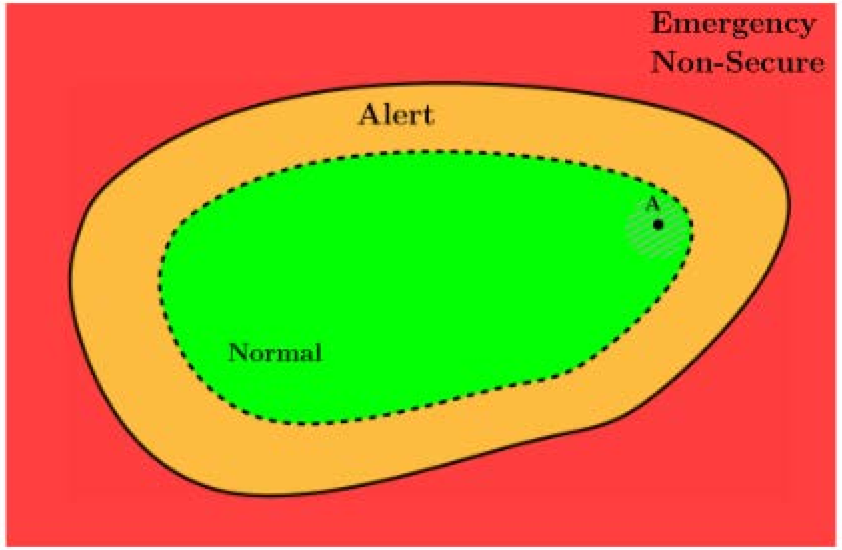


Chapter 8: Modelling preventive and corrective actions using linear formulation, Van Acker T., Van Hertem D., in *Dynamic vulnerability assessment and intelligent control for sustainable power systems, 2018*

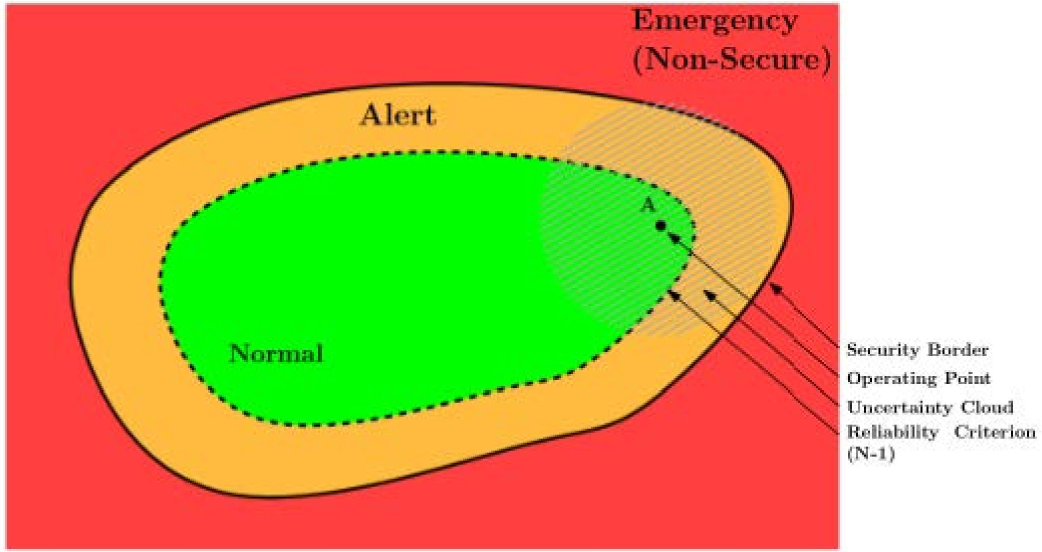
State-space representation with uncertainties

- The location of the operating point: determined by all system variables
  - System variables: Active and reactive power injections, settings of phase-shifting transformers
- State space = multi-dimensional
  - Number of dimensions = number of constrained system variables

Reduced uncertainty

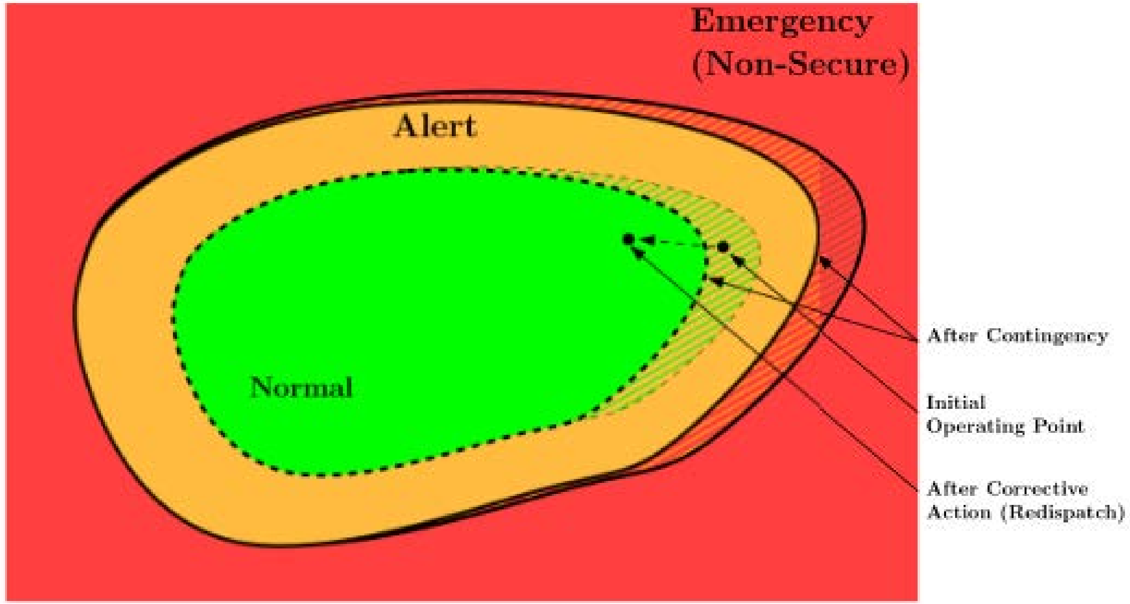


Increased uncertainty

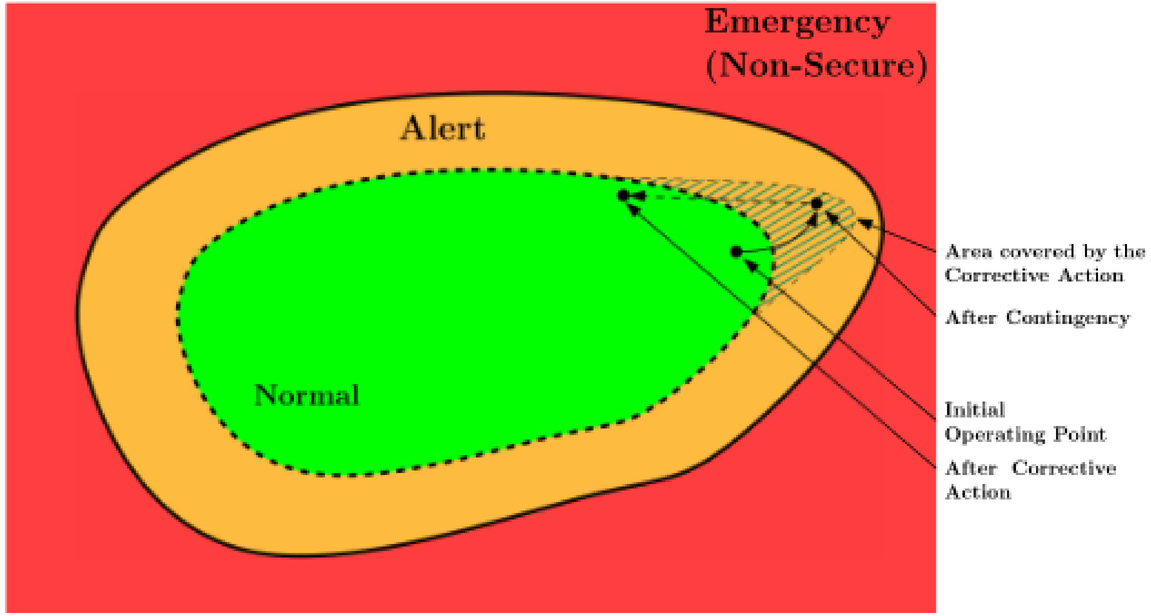


State-space representation with outages

Line outage



Generator outage

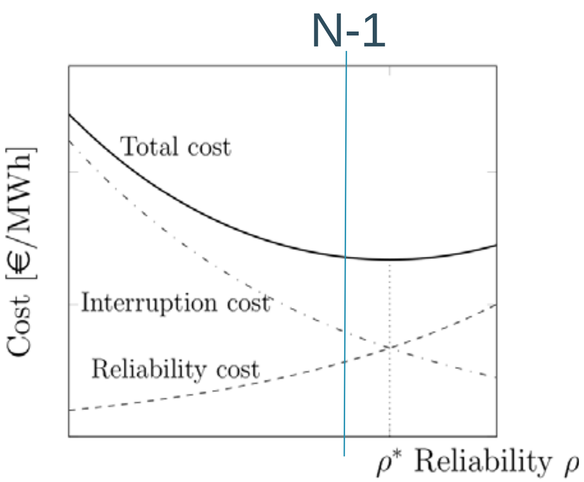


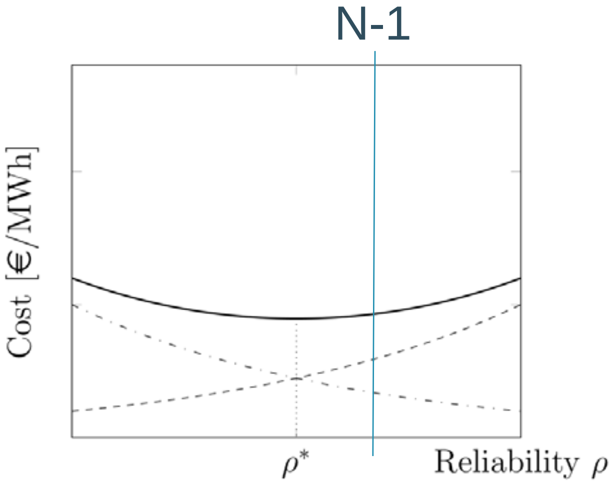
Beyond the N-1 criterion

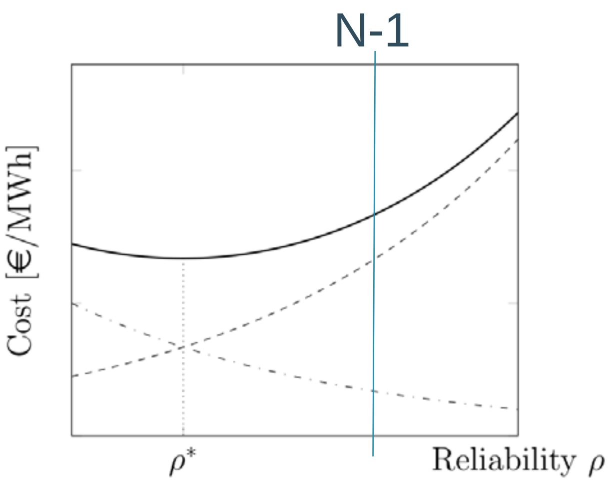
Is the application of N-1 optimal in all cases?

Risk = Probability x Severity

N-1 versus optimal reliability management







Reliability cost = cost to obtain a certain reliability level

Interruption cost = *value of lost load* x *energy not supplied*

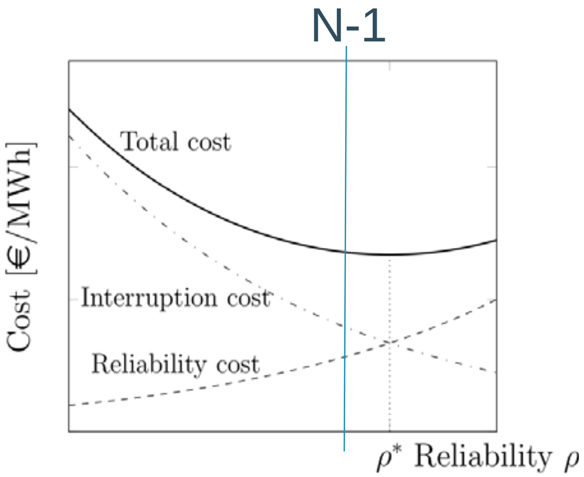
Interruption cost determined by value of lost load

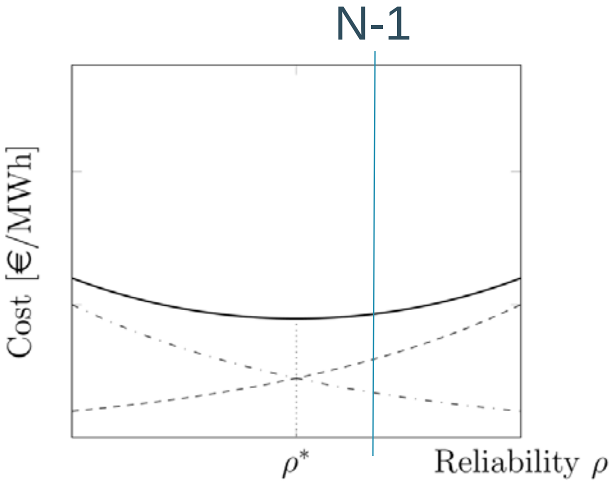
- Value of lost load (VOLL) = Cost of unserved energy
- VOLL depends on many factors:
  - Interruption time: season, day of the week, time of the day;
  - Interrupted consumers: residential, commercial, industrial, public;
  - Interruption duration;
  - Weather at the time of interruption;
  - Number of consumers affected;
  - Current reliability level;
  - Advance notification of the interruption;
  - Mitigating measures.
- Mostly simplified to a single value

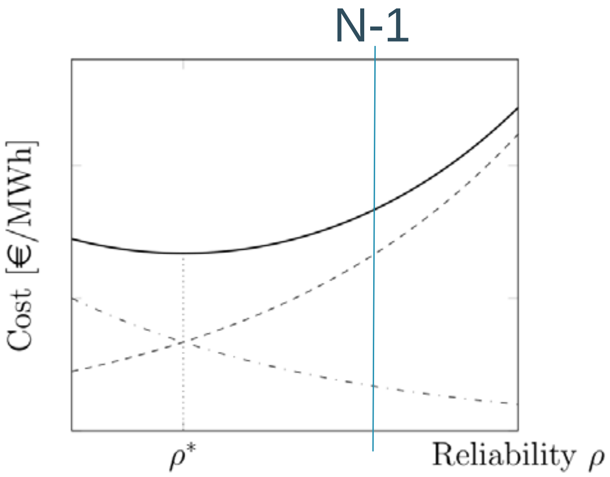
Table: Great Britain VOLL as a function of time characteristics and consumer groups (London Economics, 2013, Table 1 and Table 2). Expressed in [2015€/MWh].

	Not winter				Winter			
	Weekday		Weekend		Weekday		Weekend	
	Peak	Not peak	Peak	Not peak	Peak	Not peak	Peak	Not peak
Residential	11,093	8,081	10,753	12,946	12,757	10,571	11,952	13,730
SMEs	44,077	42,849	38,749	39,722	51,284	45,551	41,224	46,306

N-1 versus optimal reliability management







Reliability cost = cost to obtain a certain reliability level

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Classification of reliability criteria

Shortcomings of N-1
All consumers equally important

Consumer differentiation

Classification of reliability criteria

Shortcomings of N-1
All consumers equally important
No exact probabilities and severities

Consumer differentiation

Objective function

Classification of reliability criteria

Shortcomings of N-1
All consumers equally important
No exact probabilities and severities
Only single contingencies

Consumer differentiation

Objective function

Considered system states

Classification of reliability criteria

Shortcomings of N-1
All consumers equally important
No exact probabilities and severities
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Binary

Consumer differentiation

Objective function

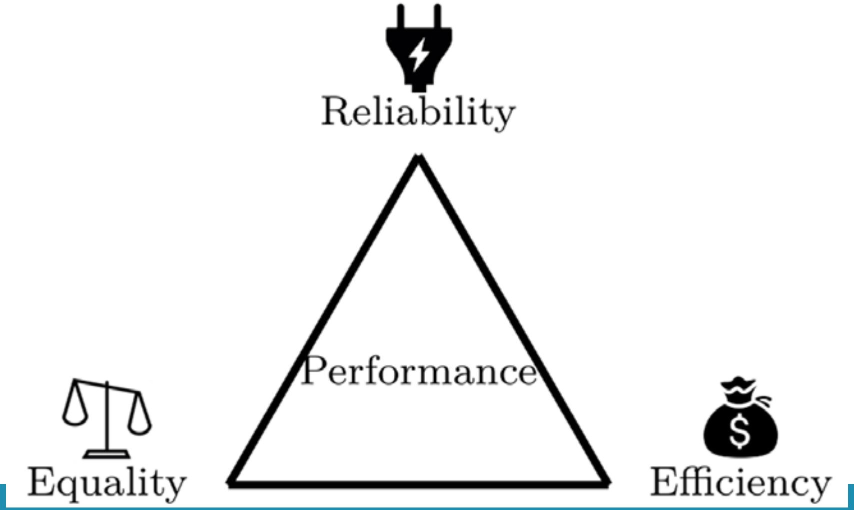
Considered system states

Non-technical constraints

Performance trilemma of reliability management

	Criteria					
	(a)	(b)	(c)	(d)	(e)	(f)
Relative expected total cost [%]	100	87.34	34.62	26.63	33.83	34.50
Relative load curtailment [min]	0.0046	0.0077	0.0046	18.87	1.83	0.19
Inequality between consumers in energy not supplied [/]	0.741	0.613	0.569	0.811	0.794	0.604

(a) Deterministic with N-1 contingency set
(b) Deterministic with different set of considered states
(c) Probabilistic without consumer differentiation
(d) Probabilistic with consumer differentiation
(e) Probabilistic with consumer differentiation and aggregated constraint on load curtailment
(f) Probabilistic with consumer differentiation and individual constraints on load curtailment



Conclusions

Take-away 1

The currently used N-1 criterion has shortcomings in evolving power systems.

http://energypost.eu/interview-andre-merlin-europe-needs-regional-system-operators-like-us/

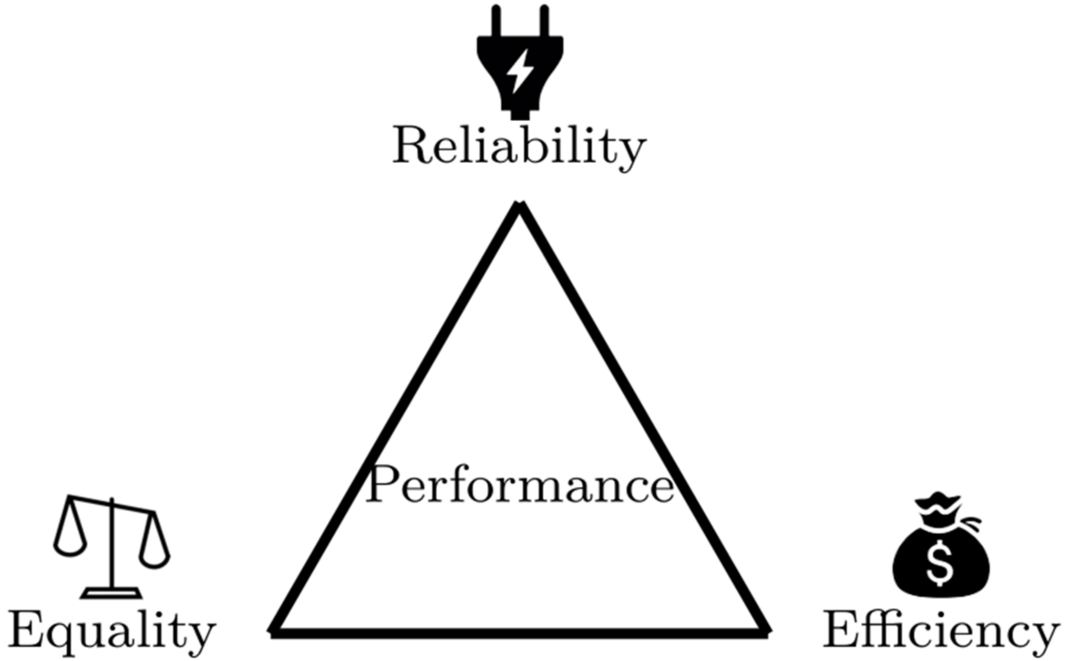
Take-away 2

Modifications of the N-1 approach pave the way for a transition from the N-1 approach to a fully probabilistic approach.

http://absfreepic.com/free-photos/download/gradual-steps-to-success-2736x3648_31699.html

Take-away 3

Multi-dimensional analysis of six reliability criteria illustrate the performance trilemma that should be dealt with to obtain socially acceptable reliability management.



Thank you!

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Research Foundation Flanders
Opening new horizons

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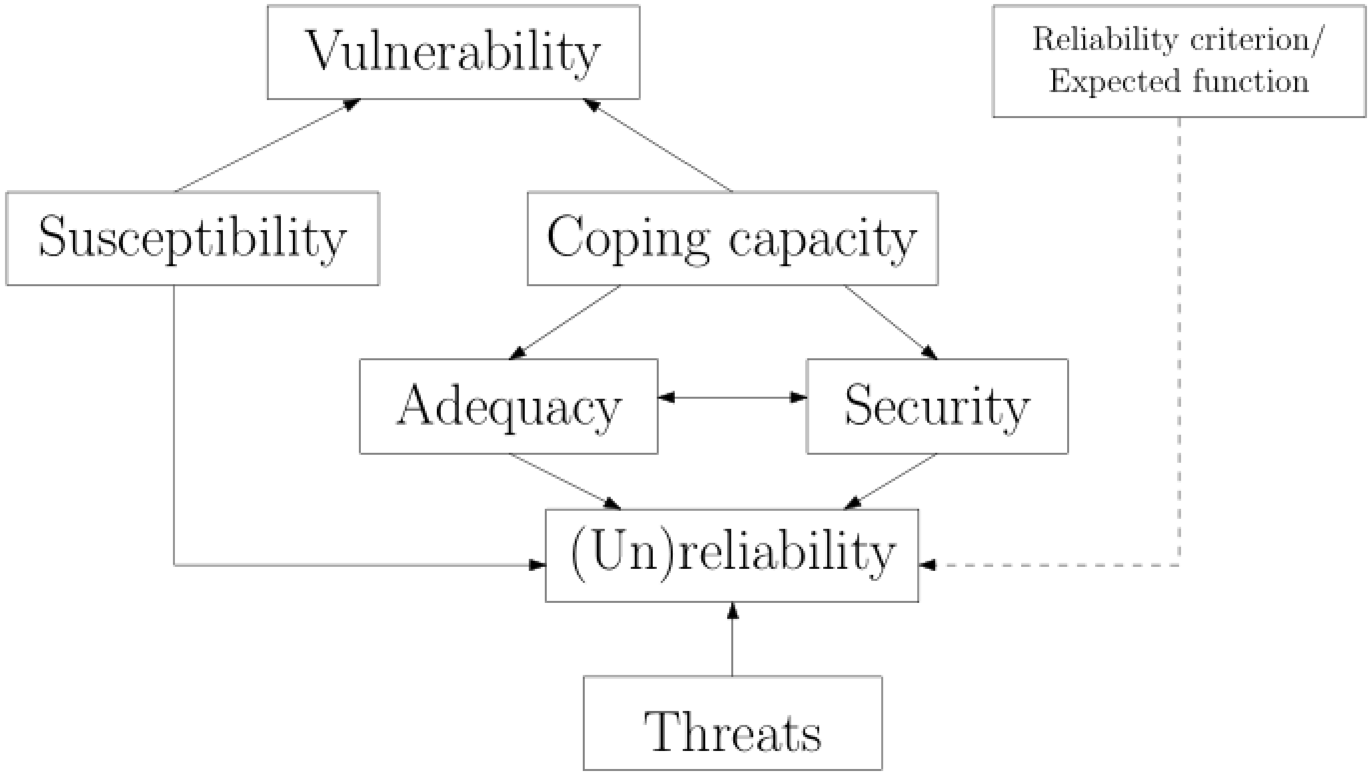
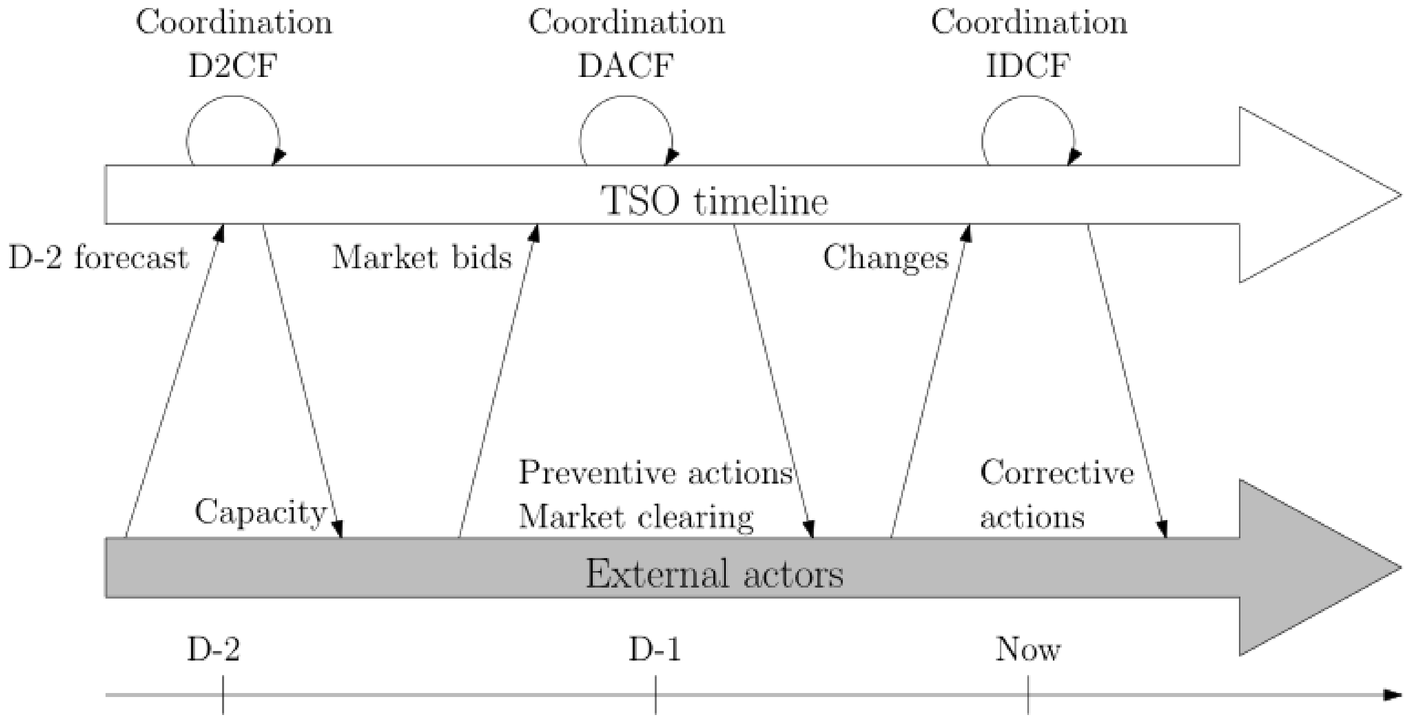
- Currently: Post-doctoral researcher KU Leuven – EnergyVille
  - Research interests: Power system reliability and Decision support for grid operators
- Jan. 2018: Doctor of Engineering Science: Electrical Engineering, KU Leuven
  - Title: Evaluation of Power System Reliability Management: Towards Socially Acceptable Short-Term Reliability Criteria
- Jun. 2013: Master of Engineering Science: Energy, KU Leuven
- Jun. 2011: Bachelor of Engineering Science: Mechanical Electrical Engineering, KU Leuven

Reliability determined by several aspects



TSO decision making influenced by external factors



D-2 Congestion Forecasts (D2CF)
Day-Ahead Congestion Forecasts (DACF)
Intra-Day Congestion Forecasts (IDCF)

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