Security Constrained Optimal Power Flow for AC/DC grids

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Overview

- Motivation
- Preventive and Preventive-Corrective SCOPF models for hybrid AC/DC system
- Test results
- Preventive-short-term-corrective SCOPF for hybrid AC/DC grid
- Extension to multi-period AC/DC SCOPF model
- Future work

Motivation

- Current reliability assessment based on N-1 criterion
- Likelihood of contingencies not considered
- May lead to cases with higher operational costs or higher risk
- Increased penetration of RES, smart grids, intra-day markets → increasing uncertainties
- Equal probabilities, static list of contingencies not optimal

Shift to Probabilistic Reliability Criteria!

- Current approaches → Preventive security and Preventive-corrective security
- Preventive-corrective : opportunity for trade-off between costs of measures and system risk

Quantitative assessment of preventive measures and system risk

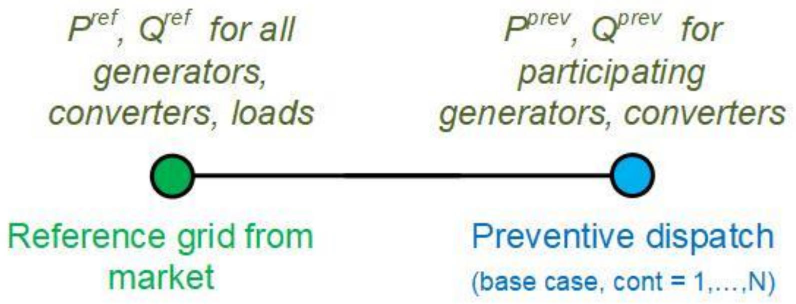
- Development of HVDC grids - fully controllable exchange between AC and DC grids
- Flexibility from AC/DC converter (active as well as reactive power)
    - preventive measures
    - fast corrective actions (smaller time constants)
- More economical than re-dispatch, load curtailment

Inclusion of HVDC in reliable grid operation !

Preventive SCOPF model for hybrid AC/DC grid

- Objective : To minimize the preventive redispatch cost

- Decision variables:
  - Generator active power redispatch in base case
  - Converter ac side active power redispatch in base case



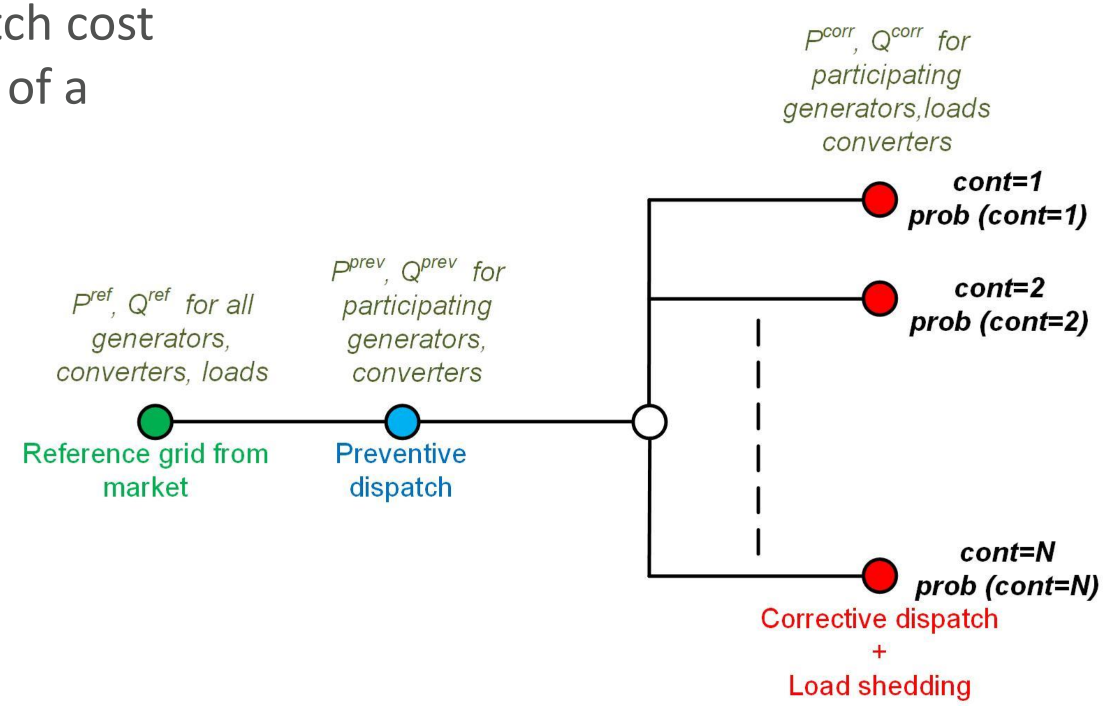
$$min \sum_{g=1}^{N_g} \left|\Delta P_g^{prev}\right| . C_g^{prev} + \sum_{c=1}^{N_c} \left|\Delta P_c^{prev}\right| . C_c^{prev}$$

Preventive actions cost

Preventive-Corrective SCOPF model for hybrid AC/DC grid

- Objective : To minimize total of preventive redispatch cost and corrective risk, which is equated to probability of a contingency times the corrective redispatch cost

- Decision variables:
  - Base case
    - Generator active power redispatch,
    - Converter ac side active power redispatch
  - Contingency case
    - Generator active power redispatch
    - Converter ac side active power redispatch
    - Active power component of load shedding



$$\min \sum_{g=1}^{N_g} |\Delta P_g^{prev}| . C_g^{prev} + \sum_{c=1}^{N_c} |\Delta P_c^{prev}| . C_c^{prev} + \sum_{cont=1}^{N} prob_{cont} \cdot \left(\sum_{g=1}^{N_g} |\Delta P_g^{corr}| . C_g^{corr} + \sum_{l=1}^{N_l} |\Delta P_l| . VOLL + \sum_{c=1}^{N_c} |\Delta P_c^{corr}| . C_c^{corr} \right)$$

First stage = Preventive actions cost

Second stage = Corrective risk

Constraints - SCOPF model for hybrid AC/DC grid

- Equality constraints
  - AC grid active and reactive power flow equations
  - DC grid active power flow equations
  - Nodal balance equations (KCL) for AC and DC nodes
  - Converter station power flow equations
    - Transformer active and reactive power flows
    - Filter reactive power flow
    - Phase reactor active and reactive power flows
    - Converter power balance equations and losses

- Inequality constraints
  - Generator active power and reactive power limits
  - Load active power and reactive power limits
  - Nodal (AC and DC) voltage limits
  - AC branch thermal limits
  - DC branch flow rating limits
  - Converter ac side - active power and reactive power limits, current limits
  - Converter dc side - active power limits, current limits
  - For LCC configuration, firing angle limits

INNOVATIVE TOOLS FOR OFFSHORE WIND AND DC GRIDS

Implementation of AC/DC SCOPF models

- Implementation of SCOPF (Security Constrained Optimal Power Flow) model for hybrid AC/DC grid using Julia/JuMP platform

- Built on:
  - PowerModels.jl package (power system optimization toolbox developed by the Los Alamos National Lab)

    https://github.com/lanl-ansi/PowerModels.jl
  - Extension packages PowerModelsACDC.jl (https://github.com/hakanergun/PowerModelsACDC.jl) and PowerModelsReliability.jl (https://github.com/frederikgeth/PowerModelsReliability.jl)

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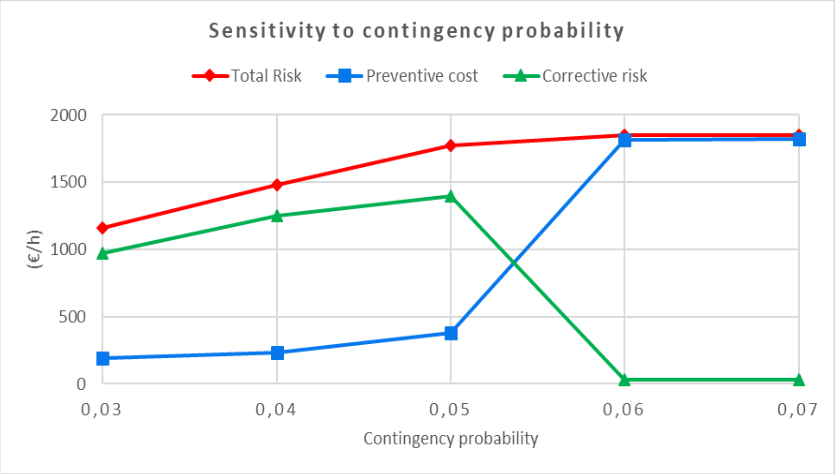
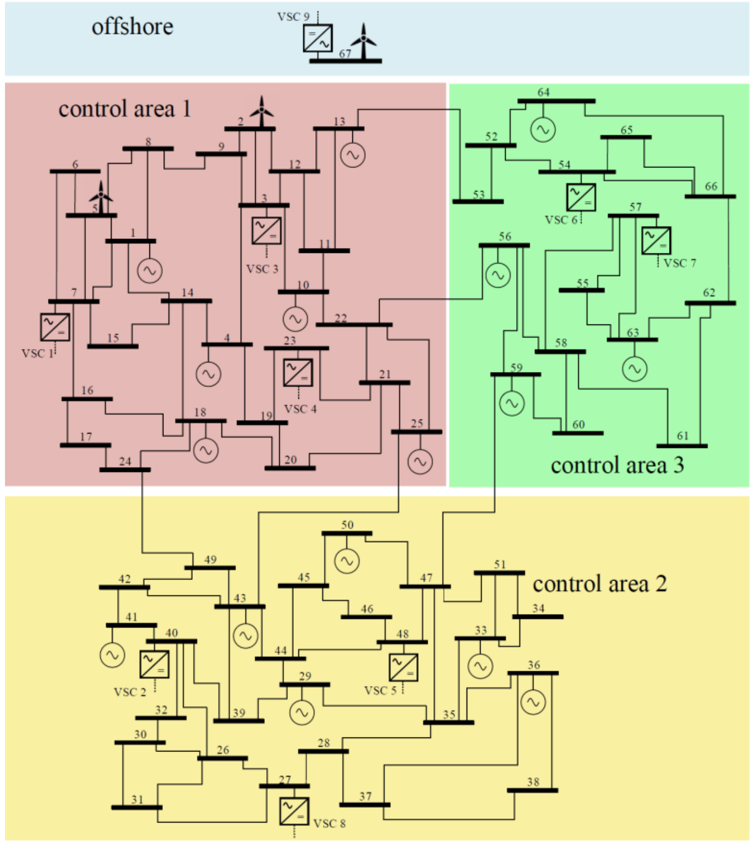
Test Results

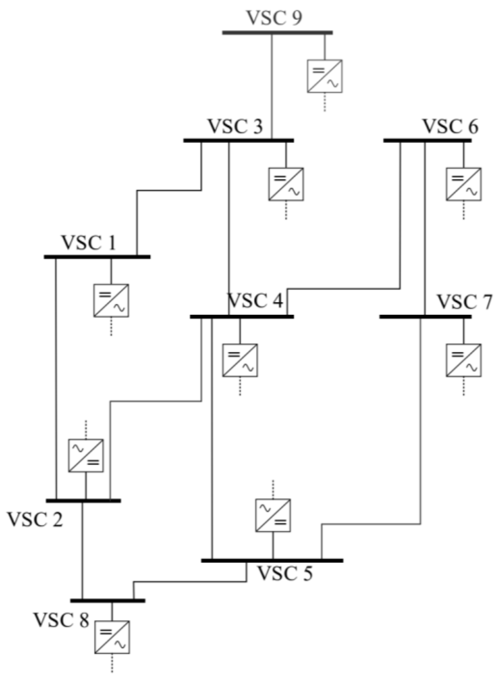
67 bus system - Impact of contingency probability on preventive-corrective redispatch

- 67 AC bus AC/HVDC Overlay system
- 17 synchronous generation units and 3 wind farms
- 9 Voltage Source Converters (VSCs)
- CostCorr/CostPrev = 10 for generators and VSCs
- 102 AC lines and 11 DC lines
- 13 critical contingencies realized





(a) AC grid topology



(b) DC grid topology

Source: Sass, F., Sennewald, T., Marten, A., Westermann, D., “Mixed AC high-voltage direct current benchmark test system for security constrained optimal power flow calculation”, IET Gener. Transm. Distrib., 2017

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Test Results

67 bus system – Comparison of preventive and preventive-corrective security

- Tripping of AC branch 2-12 considered (probability = 0,005)
- CostCorr/CostPrev = 10 for generators and VSCs

Preventive-Corrective AC/DC SCOPF

Converters participate in preventive and corrective stages

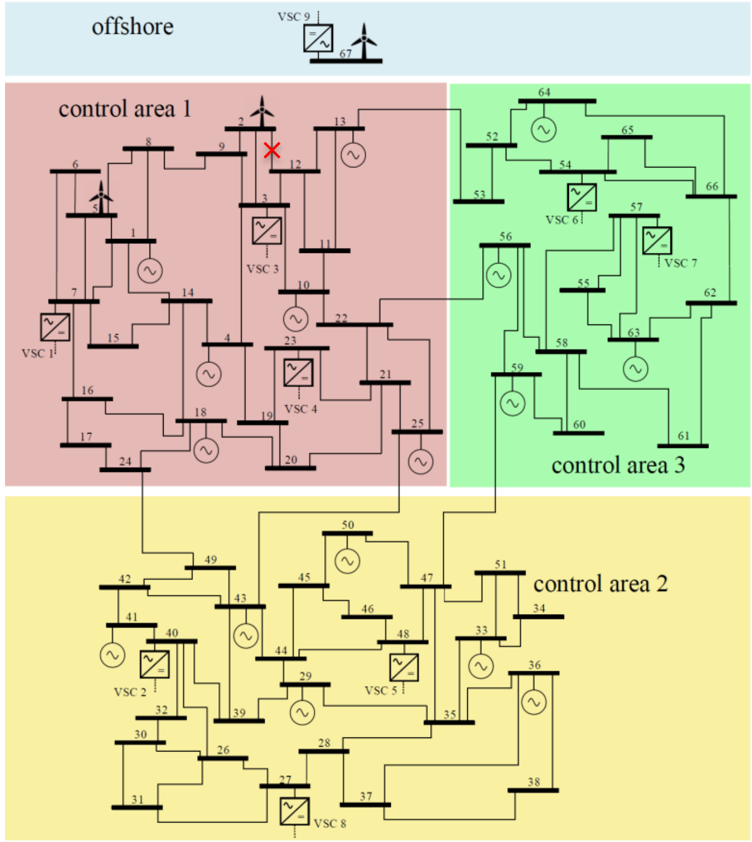
Total Risk (€/h)	First stage/Preventive cost (€/h)	Second stage/Corrective risk (€/h)
7,89	0	7,89

Preventive Generator Redispatch (MW)	Preventive Converter Redispatch (MW)	Corrective Generator Redispatch (MW)	Corrective Converter Redispatch (MW)
0	0	9,93	58,6

Converters participate in preventive stage only

Total Risk (€/h)	First stage/Preventive cost (€/h)	Second stage/Corrective risk (€/h)
12,615	0,0336	12,581

Preventive Generator Redispatch (MW)	Preventive Converter Redispatch (MW)	Corrective Generator Redispatch (MW)	Corrective Converter Redispatch (MW)
0,00338	0	25,2	-



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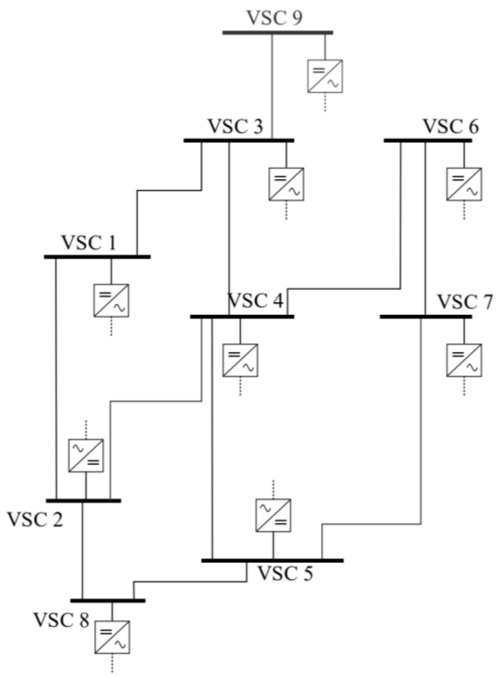

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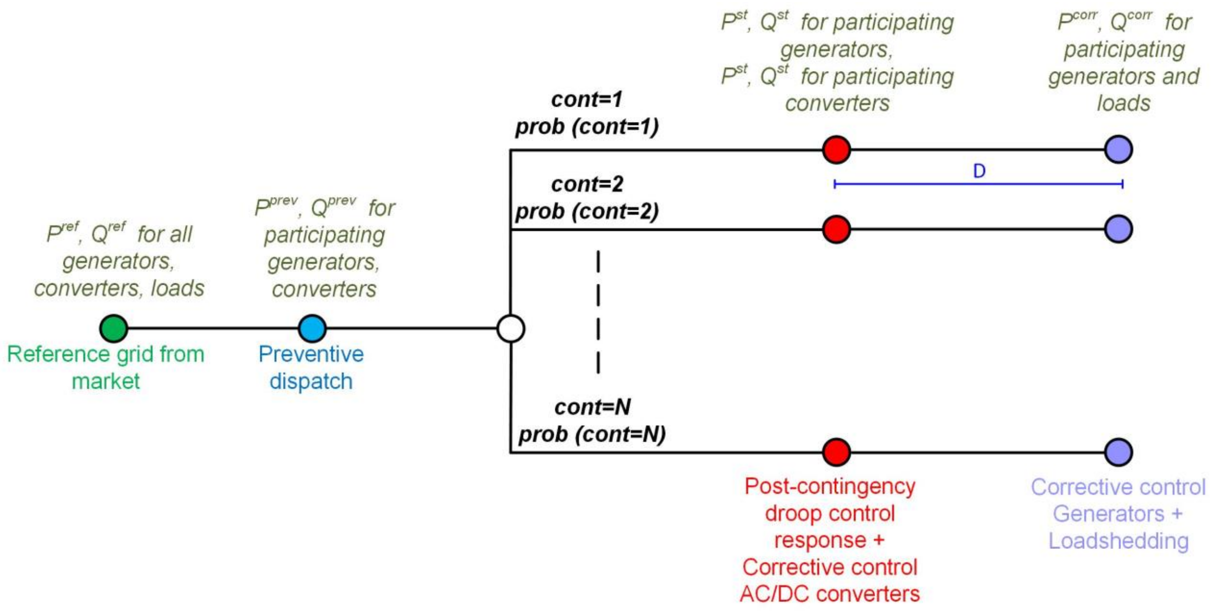
Preventive AC/DC SCOPF

Preventive cost (€/h)	
355,53	
Preventive Generator Redispatch (MW)	Preventive Converter Redispatch (MW)
32,39	31,6

Current work

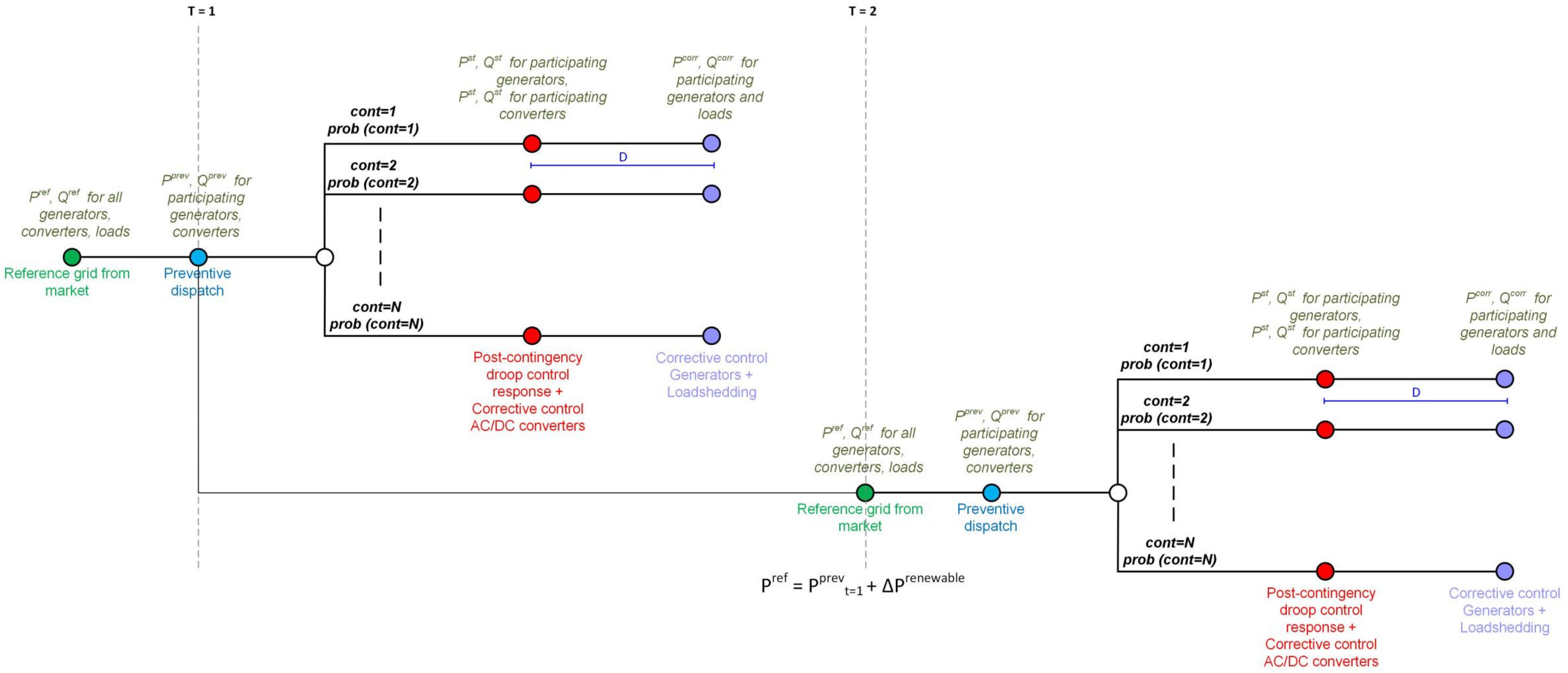
Preventive-short-term-corrective SCOPF for hybrid AC/DC grid

- Implementation explicitly considering delays of different control actions
- Evaluate flexibility offered by fast dynamics of AC/DC converters
- Capture fast control response of AC/DC converters in short-term (ST) stage
- Slower generator redispatch as corrective stage
- Preventive SCOPF as reference problem to assess impact of different stages of control



Preventive-short-term-corrective SCOPF model (single time instant) for AC/DC system

Extension to multi-period AC/DC SCOPF model



Future work

- Analysis for multi-period AC/DC SCOPF model based on test cases
- Comparison between the single time instant and multi-period models for resulting costs and risk

Thank you!

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"Uncertainty is a very good thing: it's the beginning of an investigation, and the investigation should never end." Tim Crouch

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