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Convex Relaxations of Chance Constrained AC Optimal Power Flow

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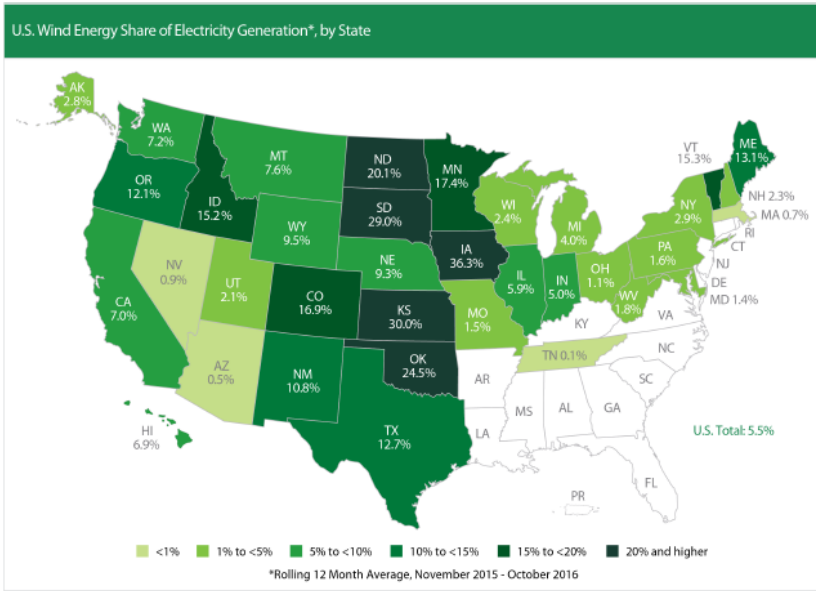
Why Consider Uncertainty?

Development of redispatch measures in German transmission grid (2016: 31.5 % RES)

Source: Bundesnetzagentur



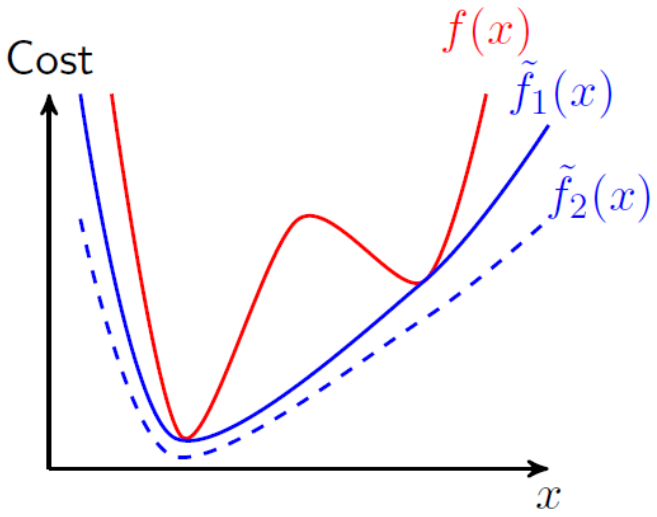
Source: AWEA

⇒ New tools necessary for power system operation of AC grids under uncertainty which are able to:

- anticipate forecast errors to maintain a secure system operation
- define a-priori suitable corrective control policies

Why Convex Relaxations?

- AC optimal power flow problem non-linear & non-convex
  - No guarantee obtained solution is global optimum
  - Distance to global optimum cannot be specified (cost)
- Semidefinite relaxation transforms AC-OPF to convex semi-definite program (SDP)



$\Rightarrow$ Under certain conditions, obtained solution is the global optimum to the original AC-OPF (Zero relaxation gap in work by Lavaei and Low[1])

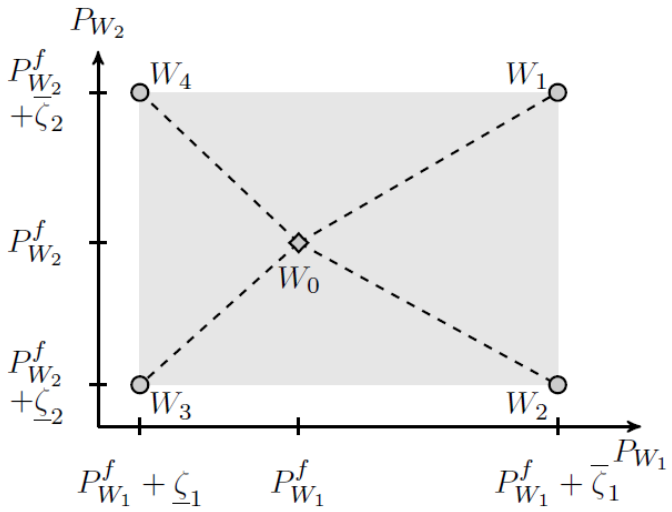
[1] Javad Lavaei and Steven H Low. "Zero duality gap in optimal power flow problem". In: *IEEE Transactions on Power Systems* 27.1 (2012), pp. 92–107

What this paper is about?

- First formulation of a chance-constrained OPF with convex relaxations for meshed transmission grids
  - Convex optimization (SDP) is more robust → OPF based on SDP can solve systems with more than 10,000 buses where AC-OPF fails[2].
  - Finds the global optimum or, at least, provides a distance measure to the global optimum
- We consider two uncertainty sets
  - Rectangular Uncertainty Set (Randomized and Robust Optimization)
  - Gaussian Uncertainty Set

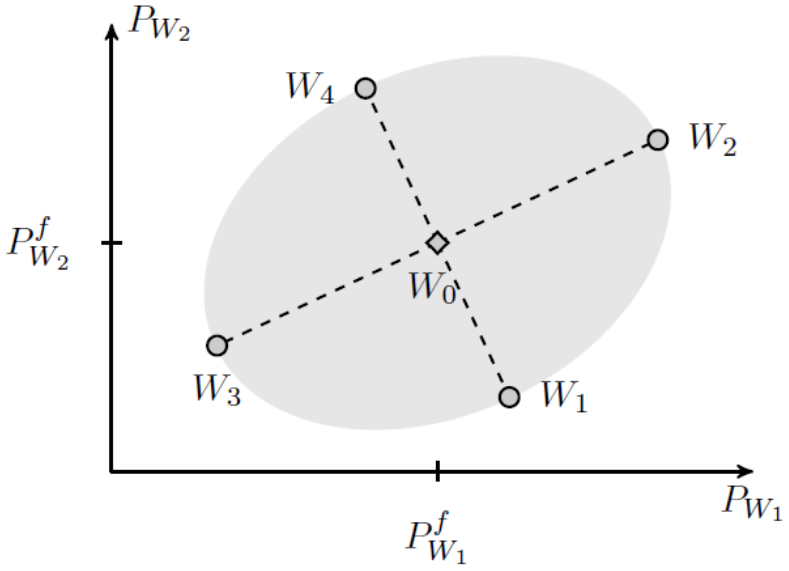
[2]A. Eltved, J. Dahl, and M. S. Andersen, "On the Robustness and Scalability of Semidefinite Relaxation for Optimal Power Flow Problems," ArXiv e-prints, Jun. 2018.

Randomized and Robust Optimization



- We use a piecewise affine policy which interpolates system state between forecasted system state W_0 and vertices of the uncertainty set W_{1-4}.
- That is, we compute the exact AC-OPF solution at each of the vertices and at the forecasted system state.
- As result of piecewise affine approximation, chance constraints are convex.
- Using robust optimization, it is sufficient to enforce chance constraints at the vertices of the uncertainty set.

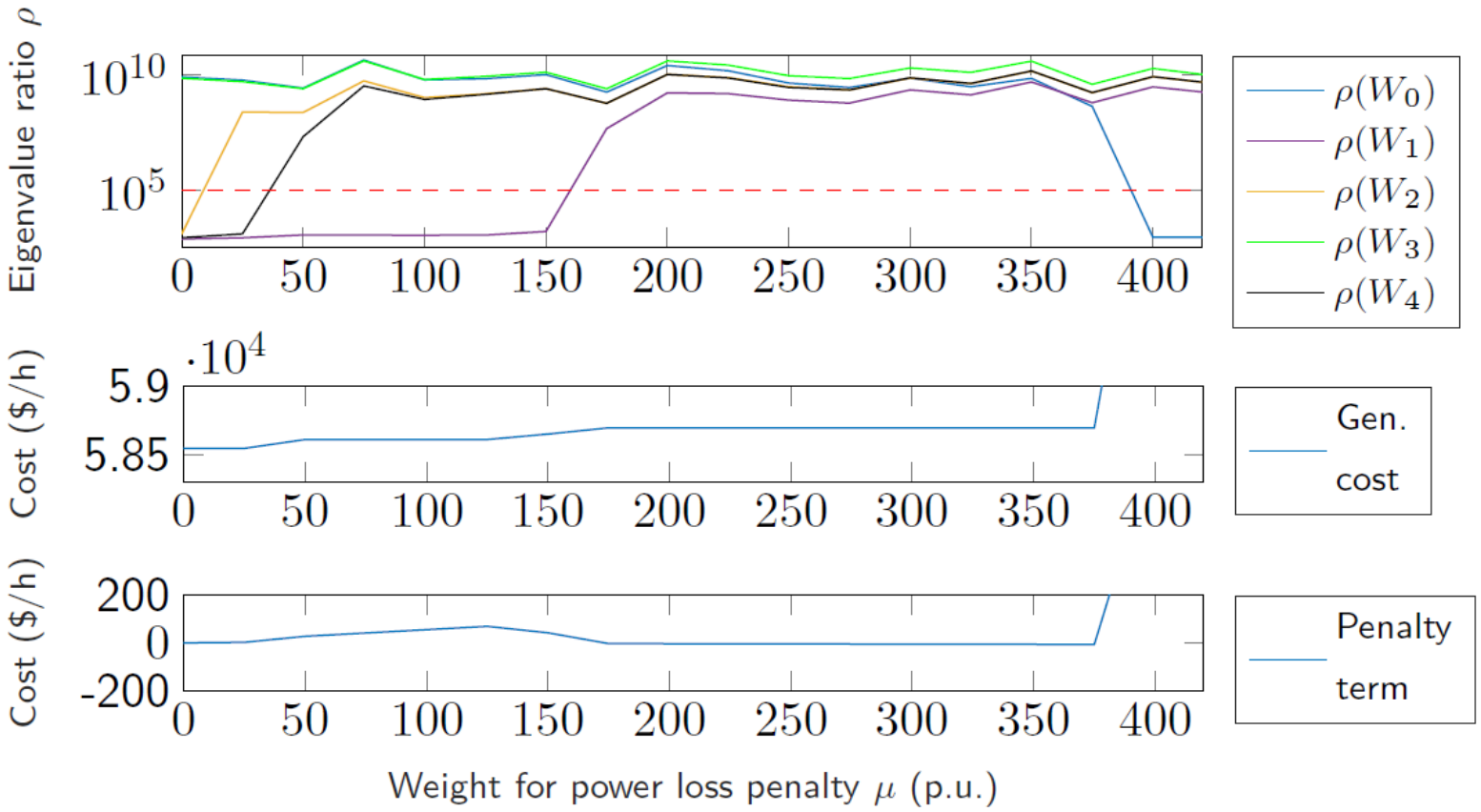
Analytical Reformulation for Gaussian Distributions



- Piecewise affine policy which interpolates system state between forecasted system state W_0 and end-point of the ellipsoid axes of the uncertainty set $W_{1\text{-}4}$
- Consider correlation of the uncertain variables
- Analytical reformulation of the linear chance constraints as SOC constraints

Investigating Relaxation Gap

... for a IEEE 24 bus test system with 2 wind farms and rectangular uncertainty set.



$\Rightarrow$ Near-global optimality guarantee of 99.74%.

Conclusions

- First formulation of a tractable chance constrained AC-OPF using the semidefinite relaxation
- Testing our algorithms to larger case studies and using realistic forecast data
- Current work includes
  - Security constraints and decomposition methods to enhance scalability: http://www.chatziva.com/publications/Venzke_Chatziv_PSCC2018.pdf
  - Interconnected AC and HVDC Grids: https://arxiv.org/pdf/1804.00035.pdf
  - Chance-constrained SOC-OPF and recovery of AC-feasible solutions: https://arxiv.org/pdf/1804.05754.pdf