DOE GMLC Project 1.4.18 “Computational Science for Grid Management”

Use Case 1: Security-constrained AC OPF under uncertainty

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Context/Need: In current practice, power is dispatched from generators based on economic considerations and assumes everything is deterministic. Many elements, however, are unknown, like load, renewable energy outputs, equipment failure, etc. In current practice, this is addressed by ensuring there is a sufficient amount of reserves in the grid to handle this uncertainty. This solution may result in inappropriate margins (possibly even too low under some circumstances; but too high in most) when increasing renewable penetration. There is a need to (re)frame the OPF problem so that it explicitly models the stochasticity and then develop approaches that can tractably solve those models. We note that SCOPF under uncertainty is central to many analyses [1],[2],[3], though solutions and software at scale are lacking. Therefore better solvers for this problem will impact many areas beyond the application targets chosen.

Problem: Minimize objective (power generation cost) while fulfilling the demand and satisfying the power flow physics and generation and transmission technological constraints for a given set of prescribed contingencies (line, bus, or generation failures) and uncertainty realizations (wind and solar power real value, equipment state).

Applicability:

- Preventive control considering voltage stability and penetration of renewable energy (extension of [4]).
- Computation of reactive reserve margins under renewable energy uncertainty (extension of [5]).
- Effect of load voltage dependence under DER deployment on reliability and cost/pricing;

Mathematical representation:

$$\min_{P_0,\ldots,P_C,V_0,\ldots,V_C} \quad (1) \quad c(P_0)+\sum_{c\in C,s\in S} c(P_{c,s})$$

$$\text{subject to:} \quad (2) \quad g^{pf}(P_0,V_0)=0\,,\, g^{pf}_{c,s}(P_{c,s},V_{c,s})=0, \quad \forall c\in C, s\in S$$

$$(3) \quad -P^{line}_{max}\le g^{line}(P_0,V_0)\le P^{line}_{max}$$

$$(4) \quad -P^{line}_{max}\le g^{line}(P_{c,s},V_{c,s})\le P^{line}_{max} \quad \forall c\in C, s\in S$$

$$(5) \quad |P_{c,s}-P_0|\le P^{ramp}_{max} \quad \forall c\in C, \forall s\in S$$

Notation:

C,S – set of contingencies and stochastic scenarios respectively; index “0” indicates the base case (no contingency)

$P_{0,}$ V_0 - power flow variables. For example P_0 denotes active and reactive power for each generator and V_0 denote voltage angle and magnitude at each bus in a polar coordinate-based formulation.

$P_{c,s,}$ Vc,s - same as above but contingency, scenario specific.

(1) defines the objective: an average cost over the contingencies and the base case.

(2) describes the power flow balance over the network both for the base case and for each contingency.

(3) and (4) describes line constraints.

(5) describes the max allowed generation ramp-up/down specific to each contingency.

Data Needs: power system data, cost coefficients, list of contingencies, intertie or generation/load uncertainty.

Challenges: Nonlinearity of the Equations; Derivative Computation; Large Problem Size;

References:

[1] Jabr, Rabih A. "Robust self-scheduling under price uncertainty using conditional value-at-risk." IEEE Transactions on Power Systems 20.4 (2005): 1852-1858.

[2] Hamon, Camille, Magnus Perninge, and Lennart Söder. "The value of using chance-constrained optimal power flows for generation re-dispatch under uncertainty with detailed security constraints." 2013 IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC). IEEE, 2013.

[3] Capitanescu, Florin, et al. "Day-ahead security assessment under uncertainty relying on the combination of preventive and corrective controls to face worst-case scenarios." PSCC proceedings Stockholm (Sweden) 2011 (2011).

[4] Putranto, Lesnanto Multa, et al. "Hybrid computation approach for SCOPF considering voltage stability and penetration of renewable enegy." Power Systems Computation Conference (PSCC), 2016. Power Systems Computation Conference, 2016.

[5] Capitanescu, Florin. "Assessing reactive power reserves with respect to operating constraints and voltage stability." *IEEE Transactions on Power Systems* 26.4 (2011): 2224-2234.