An Intrinsic Network Performance Metric for the Optimal Transmission Expansion Problem: Maximizing the Volume of Feasible Bus Injections

Official Title of Funded Project: "Optimization and Control of Electric Power Systems"

C.L. DeMarco, F.B. Thiam, and B.C. Lesieutre
Department of Electrical and Computer Engineering
University of Wisconsin-Madison
corresponding author: demarco@engr.wisc.edu

Abstract

The growing role of new technologies for future electric generation (e.g., wind, photovoltaic, solar thermal), and the great uncertainty in their potential geographic location, presents huge challenges to existing methods in transmission expansion planning and optimization. Typical strategies in use today seek transmission additions that minimize a long time horizon combination of operating costs and capital costs in very specific generation expansion/load growth scenarios. Recently, more sophisticated stochastic recourse approaches have sought to capture timing characteristics of transmission expansion decisions. However, even these improved approaches typically employ small numbers of possible generation and load growth scenarios; for example, a very comprehensive on-going study over the whole of the U.S. Eastern Interconnect seeks to capture the range of possibilities using only eight scenarios. As a fundamentally different philosophy, our work proposes a measure of transmission performance that is intrinsic to the network itself, without dependence on specific generation/load scenarios, to provide a system-wide measure of the network's power delivery flexibility. In particular, our proposed network performance metric is the generalized volume of the set bus power injections feasible under line flow constraints in the given transmission network. Using the standard construct of power transfer distribution factors (PTDFs), we demonstrate that such a measure is easily defined analytically, and is closely tied to the determinant of the bus susceptance matrix describing the electrical properties of a bulk transmission network. To address the combinatoric nature of the line placement problem (potentially [n choose 2] candidate line placements, with n numbering in the tens of thousands), we demonstrate very low computational cost heuristics to rank candidate line additions with respect to their impact on the determinant/feasible injection volume. Results of this approach are demonstrated on standard power system test cases up to 118 buses, in which the heuristic can be measured against exhaustive search of all candidate placements. In these test cases, the low-cost ranking algorithm demonstrates very high correlation with the full, exact computation of determinant/volume.

Continuing work seeks to generalize the feasible injection set volume metric, using differentiated weighting among network locations, to allow assignment of relative value to power injection flexibility at different sites. The volume measure used to date may be viewed as a multi-variable integration in which a unity weighting function is employed. Assigning spatially differentiated weighting at different nodes creates a general multi-variable integration problem. Exploiting the network structure of the problem, we demonstrate that it is possible to "pull back" from the set of feasible injections, to a simpler problem of integration over a hyper-rectangle. We will describe preliminary efforts using quadrature methods to yield tractable approaches to this very high dimension integration problem, as further steps towards effective algorithms for the optimal transmission expansion decision problem.