Three-phase OPF software for economic dispatch of continuous and discrete control assets

Nawaf Nazir, Pavan Racherla, and Mads Almassalkhi*
Department of Electrical and Biomedical Engineering
University of Vermont, Burlington, Vermont, USA
Email: mnazir, pracherl, malmassa@uvm.edu

Distribution system analysis and control requires the solution of Optimal Power Flow (OPF) equations, a mixed-integer/nonlinear, time-coupled problem in its original form. Many problems in distribution system analysis are computationally challenging given the combinatorial number of possibilities. From an optimization viewpoint, the task is complicated further by the choice of a representative timeframe: a "typical" hour, day, week, month, or year? Simplifications of the AC power flow and associated constraints of the OPF problem are achieved by some form of approximations to enable a tractable implementation. These simplifications, however, can have limited value in helping utilities solve high-level problems for renewable-energy-based, data-rich distribution systems, such as coordination of DERs under extreme penetrations of solar PV, optimal battery sizing/siting/dispatch, and active network management. These challenges call for a creative approach to scalability of optimization algorithms that remains faithful to the original problem.

Our approach develops convex, 3-phase optimization algorithms and software for the dispatch of controllable grid assets that are fast-continuous (e.g., EVs, batteries, inverters) and slow-discrete (e.g., cap banks and LTCs). This leads to a bilevel coordination framework wherein the fast-continuous and slow-discrete assets are dispatched on different timescales. Furthermore, this approach can track economic reference signals from wholesale energy markets and handle the temporal coupling between energy states.

For the slower (e.g., hourly) timescale, a predictive voltage-positioning (VP) problem is formulated in a 3-phase distribution system to maximize voltage margins under significant renewable penetration by leveraging discrete assets to maintain desired economic energy targets. The VP problem minimizes deviations in voltage from nominal values based on a pre-defined narrow range, which is designed by considering voltage-reactive power sensitivities to reduce the need for using fast (flexible) reactive resources on the slower time-scale. When solved, VP produces a look-ahead schedule for discrete control elements, which are now fixed in the fast time-scale problem. The fast problem can then focus on optimizing minutely grid voltages using continuous resources such as virtual batteries, DERs, and inverters, ensuring that economic targets are met under significant renewable variability. To achieve this, a multi-period SOCP problem is formulated for a convexified 3-phase AC model, whose solution is then used to hot-start a non-convex NLP formulation, thereby guaranteeing realizability of the optimal solution.

These algorithms are to become part of an existing open-source software suite called the interactive Distributed Grid Analytics (iDGA) platform at the University of Vermont. The platform is set up to ingest AMI/SCADA data and common industry network formats (e.g., EPRI-DRIVE and CYME) and visualize 3-phase OPF solutions and load flows. Validation of all work is performed on a mix of large and medium 3-phase AC test models using GridLab-D and real (utility-supplied) data.

*Support from U.S. DoE award number DE-EE0008006 is gratefully acknowledged.