DISTRIBUTED ALGORITHMS FOR POWER SYSTEM MONITORING AND CONTROL

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RESEARCH SUMMARY

Tomorrow's electric power grid will have many components distributed over a large geographic area, necessitating distributed, scalable solutions to monitor and control the future grid. Our work on Blue Waters focuses on developing distributed algorithms for the security-constrained optimal power flow problem (SC-OPF). SC-OPF is a large-scale, nonlinear optimization problem that economically balances supply and demand under certain physical and operational constraints. It must be solved within five minutes or faster to operate the grid in a responsive manner to contingencies. The main computational burden is solving a series of large, sparse linear systems. In our work, we develop specialized solvers to exploit the sparsity pattern induced by the underlying network structure and physical laws of power networks. By using Blue Waters, we can push the boundary of the size of the largest SC-OPF problem that is solvable within required time limits.

Increasing power demands, aging infrastructure, and growth in renewable energy production necessitate new strategies for grid operations. To achieve reliable operations in this setting, it is important to shift away from centralized control paradigms to distributed approaches that 1) allow for quicker solution times by decomposing the problem to be solved in parallel and 2) avoid communication bottlenecks that result from all data and measurements being sent to a centralized location (Fig. 1). Since power systems are interconnected systems, decoupling such problems is challenging.

Our work on Blue Waters focuses on developing distributed second-order algorithms for the SC-OPF problem in power systems. SC-OPF is an optimization problem that seeks the amount of power to be generated from each power plant to minimize costs under certain physical and operational constraints. A fast, robust solution to SC-OPF remains an important challenge in power system operations [1].

SC-OPF is a large-scale, nonlinear optimization problem that ideally can be solved within five minutes or less to operate the grid in a responsive manner to contingencies (i.e. equipment failures). We explore the use of primal-dual interior point methods to solve SC-OPF. The main computational burden of this method is solving a series of large, sparse linear systems. In our work, we develop specialized solvers to exploit the sparsity pattern induced by the underlying network structure and physical laws of power networks (Fig. 2). In particular, we adapt domain decomposition methods, typically used for partial differential equation solvers, since our problem has a similar structure. Namely, different contingencies are loosely coupled only via the power generation decision variables. Furthermore, the physical laws governing the power grid (e.g. Kirchhoff's laws) can be written as a set of equations involving only local and neighboring quantities. By adapting domain decomposition techniques, we can parallelize across different contingencies and power decision variables the main computational bottleneck of our algorithm, which serially requires 98% of runtime. If grid operators adopt a parallelized strategy, important improvements in runtime can be made, which is critical for real-time operations.

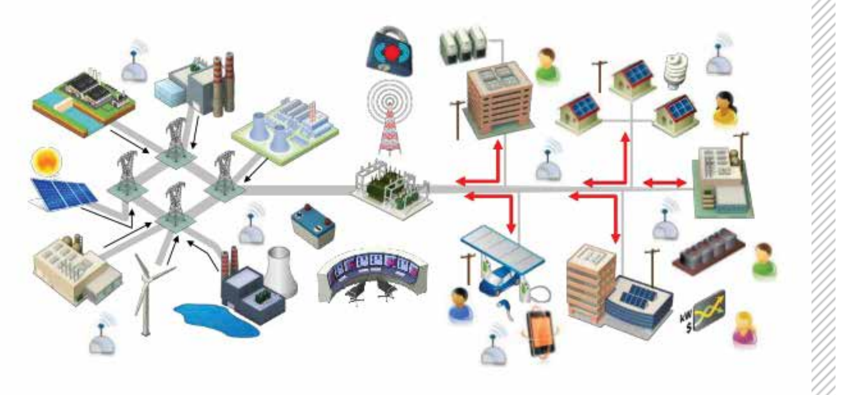

FIGURE 1: Tomorrow's power grid will have many components distributed over a large geographic area on both the supply and demand side. Rather than processing all information at the central control center, distributed solutions will provide scalable, large-scale coordination of the many active points in the grid. Image courtesy of Electric Power Research Institute (EPRI).

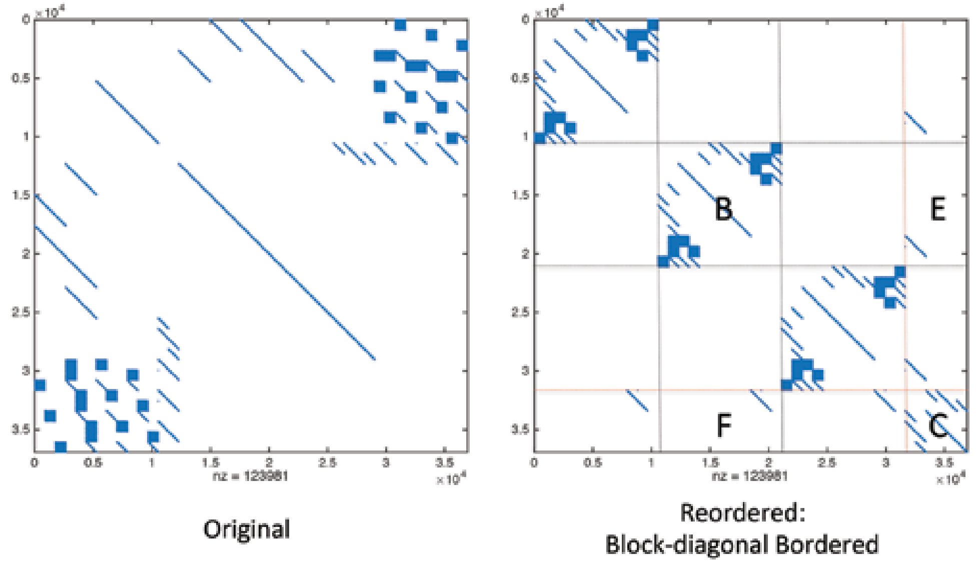

FIGURE 2: The structure of the system matrices involved in the security-constrained optimal power flow can be reordered so that it is amenable to domain decomposition techniques.

WHY BLUE WATERS

Working with Blue Waters allows us to measure the level of parallelization required to achieve runtimes needed for real-time operation (less than five minutes). Using Blue Waters, runtimes can be tested on realistic systems with hundreds to thousands of interconnections and with hundreds to thousands of contingencies. The speed of computation limits the number of contingencies, or fault scenarios that power grid operators can ensure against when solving for the optimal operating point since the result of the computation is needed within a short time-frame for operational use. By using Blue Waters, we can push the boundary of the size of the largest SC-OPF problem that is solvable within required time limits.

I would like to acknowledge the NCSA staff for their extensive help in building the GridPACK software [2] on Blue Waters. GridPACK is a software package developed by Pacific Northwest National Laboratory that provides a framework for developing power grid applications on HPC platforms.

PUBLICATIONS AND DATA SETS

Minot, A., N. Li, and Y. Lu. A Parallel Primal-Dual Interior Point Method for Optimal Power Flow. *Power Systems Computation Conference*, Genoa, Italy, June 20-24, 2016.

Ariana Minot is in her fifth year of Ph.D. studies in Applied Mathletics at Harvard University. She plans to graduate in May 2017 and hopes to continue advancing research at the intersection of power grid engineering and scientific computing.

"After graduation, I plan to pursue a research position at a national laboratory or industry laboratory related to the electric power grid," Minot says, "Blue Waters has given me the opportunity to develop algorithms on high performance computing (HPC) platforms and learn from the wider community of Blue Waters users."