Real-time Stochastic Optimization of Complex Energy Systems on High Performance Computers

[SC13 Poster Extended Abstract]

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ABSTRACT

We present a scalable framework that computes in operationally compatible time the optimal energy dispatch under uncertainty for complex energy systems of realistic sizes.

In the US, power grid optimization problems are solved by each of the 10 independent system operators (ISOs). In the form of unit commitment (UC), such problems are the main component of day-ahead planning of generators and electricity markets and they currently are solved faster than one hour [9]. In the form of economic dispatch (ED), these optimization problems are used to balance supply and demand, and they need to be solved within several minutes [9]. The economic footprint of such problems is enormous; in the US, solving such problems results in dispatch orders to generators that are worth several billions to tens of billions of dollars per year per ISO, for a national total of hundreds of billions of dollars per year. Their critical contribution to the US economy has led to their analysis as technologies being specifically controlled by law, for example in the Energy Policy Act of 2005, Sections 1298 and 1832.

We focus on the computing challenges stemming from one such evolutionary imperative: accounting for the variability in energy supply availability that occurs when renewable energy sources such as wind are used by using optimization under uncertainty techniques such as stochastic optimization [1, 2, 7]. This results in vastly larger optimization problems, with several billion variables and constraints, because a large number of possible realizations of the uncertainty need to be considered to accurately capture the stochastic component of the problem. In addition, our models incorporate the transmission network of the State of Illinois, which contains approximately 2,000 transmission nodes, 2,500 transmission lines, 900 demand nodes, and 300 generation nodes (illustrated in Figure 1). As the problem is very large and needs to be solved within restrictive time limits, a high-end distributed memory supercomputing solution is not only useful, it is also required.

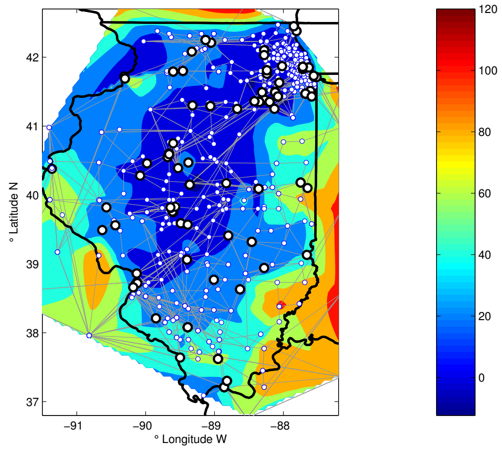

Figure 1: Network topology and snapshot of price distribution (color map).

To address this challenge we have developed PIPS-IPM [5, 4, 3], a hybrid MPI-SMP parallel solver for stochastic programming problems that uses an interior point method and implements specialized distributed-memory linear algebra. The linear algebra implementation uses a Schur complement technique to obtain a scenario-based parallelization of the computations and, despite the non-trivial decomposition pattern, achieves very high parallel efficiencies on HPC platforms.

To bridge the space between scalability and performance, needed for the real-time solution of stochastic power grid optimization problems, we have recently proposed several

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algorithmic and implementation advances inside PIPS-IPM.

First we developed a novel incomplete augmented multicore sparse factorization [6], coupled with BiCGStab Krylov subspace iterative method to ensure numerical stability and robustness. The factorization was implemented within PARDISO [8] linear solver and is capable of decreasing the execution time by approximately a factor of ten compared to previous implementation [4].

Second we address in a significantly different way the two main computational bottlenecks of our decomposition approach, namely, dense linear algebra computations and communication. For this we present implementation improvements such as mixed CPU-GPU computations and a new communication-computation pattern that make efficient use of modern architectures such as Cray XK7 and Cray XC30 and facilitate very good parallel efficiencies.

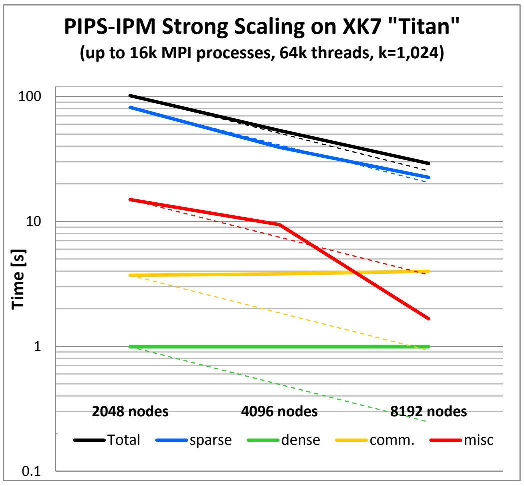

Figure 2: Strong scaling on "Titan".

Our large scale numerical experiments performed on the "Titan" XK7 machine from Oak Ridge National Laboratory, the "Piz Daint" XC30 machine from Swiss National Supercomputing Centre and "Intrepid" BG/P (80% of the machine) of Argonne National Laboratory show that it is possible to solve realistically sized problems (24-hour horizon) with thousands of scenarios in times that are considerably under one hour. To the best of our knowledge, this has not been possible before.

We also observe strong scaling efficiencies on both systems, 79.2% on "Piz Daint" and 87.0% on "Titan" (showed in Fig 2), despite the significant acceleration of the intranode computations. The largest power grid optimization problem we solved in this work is a 24-hour horizon unit commitment problem with 16, 384 scenarios that has 1.95 billion variables and 1.947 billion constraints. On 16, 384 nodes of "Titan" (87.6% of the machine) we solved sparse indefinite linear systems of size as large as 7.8 billion equations and unknowns.

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