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The University of Texas at Austin
Final Scientific/Technical Report
Fast and robust strategies for
large-scale mixed-integer
SCOPF
DE-FOA-0002690

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Project Team Members	University of Colorado Boulder
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Program Director:	Dr. Richard O'Neill
Principal Investigator:	Dr. Javad Mohammadi
Contract Administrator:	Angela D Adair <angela.adair@austin.utexas.edu>
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Public Executive Summary

This project develops scalable, computationally efficient algorithms to solve realistic large-scale power system optimization problems, including systems with more than 8,000 buses, as part of a larger series of competitions run by ARPA-E. These problems are critical because the secure and reliable operation of the power grid is becoming increasingly challenging, especially under conditions of increased uncertainty and variability. The economic feasibility of our methods is high, given that they are purely software-based solutions designed to operate power grids more efficiently. The technical effectiveness balances heuristics and approximations to provide a trade-off between speed and accuracy.

Advancements in software for power grid operations are essential as operational reliability is increasingly threatened. Better computational tools can benefit the public by providing access to reliable energy in a robust manner. Our team's approach leverages multiple techniques, including reasonable approximations of physics and data-driven methods, to reduce the complexity of the problem and uncover patterns in the chosen operational strategies.

To address these challenges, we propose breaking the grid operation problem into two sequential sub-problems: the DC and AC modules. The DC module simplifies the problem using certain assumptions (discussed in our recent paper[1,2]) to speed up computation, optimizing binary and continuous variables. These binary results are then fixed to the derived value for the next step, the AC module. In the second step, we incorporate critical AC constraints to represent the power grid (see our paper for more detials[1,2]). Our two-pronged approach enforces critical limits, like ramping constraints, to prevent issues such as abrupt device shutdowns. The DC model (module 1 in Figure 1) is solved using the mixed-integer linear solver provided by the Gurobi. The nonlinearities and non-convexities of the AC model (second module of Figure 1) are tackled using the IPOPT solver. Figure 1 illustrates an abstract representation of considered constraints.

The two sub-problems are designed to manage the computational workload of the underlying complex problem provided by ARPA-E. We use the following techniques to reformulate the original problem, eliminating quadratic terms by reformulation, relaxing nonconvex constraints, linearizing convex constraints, managing uncontrollable loads, and post-simulation calculation of power reserves. Additionally, our solution benefits from the structural representation of Jacobian and Hessian matrices, utilizing vectorized forms, and efficient storage methods for sparse matrices in a coordinated format.

We have noticed that decomposition and specialized solver approach, alongside reformulation techniques, enhance both computational effectiveness and overall efficiency.

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[1] Sharadga, H., Mohammadi, J., Crozier, C., & Baker, K. (2024, February). "Optimizing Multi-Time Step Security-Constrained Optimal Power Flow for Large Power Grids". In 2024 IEEE Texas Power and Energy Conference (TPEC) (pp. 1-6). IEEE.

[2] Sharadga, H., Mohammadi, J., Crozier, C., & Baker, K. "Scalable Solutions for Security-Constrained Optimal Power Flow with Multiple Time Steps" submitted for consideration IEEE Transactions on Industry Applications

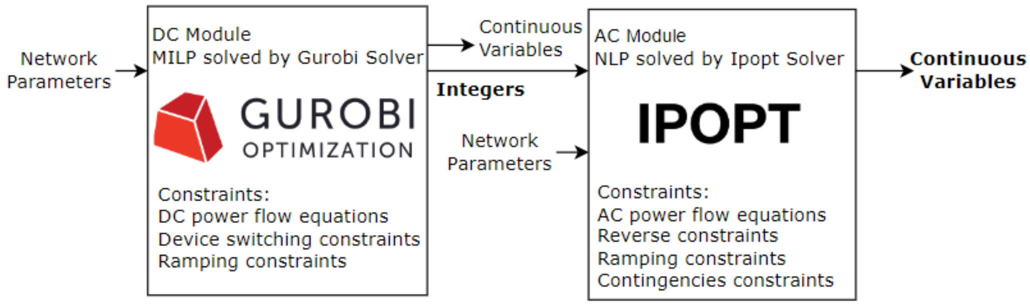

Figure 1. Our proposed two-staged solution strategy

Lesson learned: Despite great performance in trials 1,2, and 3, overlooking reserve constraints in the final round negatively impacted the overall performance of our team. Moving forward, we plan to integrate all constraints in the early trials.

Acknowledgements

The project team would like to thank ARPA-E for the financial support of this project and the Pacific Northwest National Laboratory for being so helpful and responsive with assistance with the supercomputer.

Accomplishments and Objectives

The University of Texas at Austin (UT Austin) and the University of Colorado Boulder (CU Boulder) have built a collaborative team. The core team members include Dr. Javad Mohammadi (UT Austin PI), Dr. Kyri Baker (CU Boulder, co-PI), Dr. Hussein Sharadga (Postdoc at UT Austin who received a Ph.D. from Texas A&M), and Dr. Constance Crozier (former Postdoc at CU Boulder, now Assistant Professor at Georgia Institute of Technology, who also participated in GO2).

We developed and submitted Python code for GO 3 trials 1, 2, 3, and 4, capable of handling power grids with more than 8,000 buses within the given time frame. Our team successfully participated in all trials, presented research at the INFORMS Conference and the ARPA-E Grid Software Annual Review, and continues to refine algorithms, expand data-driven methods, and disseminate findings through publications and presentations.

Table 1. Key Milestones and Deliverables.

Tasks	Milestones and Deliverables
Task 1: Register for the GO 3 Competition Challenge 3 on the competition website	All team members are registered on the GO3 website. Working off of our existing GO2 codebase, our team updated the code to adhere to the new problem formulation in GO3.
Task 2: Participate in competitive trial 1	Our team's code was submitted. The results were then evaluated for second stage improvements.
Task3: Participate in competitive trial 2	We have improved our solution in terms of speed, feasibility, and accuracy since trial 1 and we submitted our code to trial 2.
Task 4: Participate in competitive trial 3	We improved our code, enabling it to efficiently handle larger networks, and then participated in trial 3.
Task 5: Participate in competitive trail 4	We refined the code for better robustness, ensuring it always converges to a solution within the allocated time, and then submitted it for trial 4.

Project Activities

- Recruiting and Team building.
- Developing and submitting Python code for trials 1, 2, 3, and 4 of the GO 3 competition.
- Presenting research results at the INFORMS Conference: Constance gave a talk, and Hussein presented a poster.
- Showcasing the developed tool at the ARPA-E Annual Review.

Project Outputs

A. *Journal Articles*

Hussein Sharadga, Javad Mohammadi, Constance Crozier, Kyri Baker, 'Scalable Solutions for Security-Constrained Optimal Power Flow with Multiple Time Steps', IEEE Transactions on Industry Applications. (Invited Paper Under Review)

B. *Papers*

Hussein Sharadga, Javad Mohammadi, Constance Crozier, Kyri Baker, 'Optimizing Multi-Time Step Security-Constrained Optimal Power Flow for Large Power Grids', 2024 IEEE Texas Power and Energy Conference (TPEC), https://ieeexplore.ieee.org/abstract/document/10472229.

C. *Status Reports*
N/A

D. *Media Reports*
N/A

E. *Invention Disclosures*
N/A

F. *Patent Applications/Issued Patents*
N/A

G. *Licensed Technologies*
N/A

H. *Networks/Collaborations Fostered*
N/A

I. *Websites Featuring Project Work Results*
https://gocompetition.energy.gov/news
https://javadm-utexas.github.io/Homepage/projects.html
https://www.colorado.edu/ceae/kyri-baker

J. Other Products (e.g. Databases, Physical Collections, Audio/Video, Software, Models, Educational Aids or Curricula, Equipment or Instruments)

Python-based GitHub tool for optimizing power grid operations.

K. Awards, Prizes, and Recognition

- Top Three Performing Team in the ARPA-E Grid Optimization Competition Challenge 3, Trials 1, 2 and 3. Prize: $ 115,000.
- Top Five Performing Team in the ARPA-E Grid Optimization Competition Challenge 2.
- Top Ten Performing Team in the ARPA-E Grid Optimization Competition Challenge 1.

Follow-On Funding

- PI Mohammad received the Air Force Office of Scientific Research's Young Investigator Award in 2023 [Press Release]