Final Technical Report

Alternating Direction Decomposition with Strong Bounding and Convexification (ADDSBC) for Solving Security Constrained AC Unit Commitment Problems

ARPA-E Grid Optimization Challenge 3

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- This Report contains no Protected Data.

Public Executive Summary

This project aims to develop efficient and robust computational methods for solving the security-constrained unit commitment and alternating current optimal power flow problem (SC-UC-ACOPF). The SC-UC-ACOPF problem is at the center of the short-term operation of the U.S. Power Grid. It is solved every week, every day, and every 10 minutes to plan for the optimal action of electricity generation and consumption by minimizing the generation cost and maintaining power system reliability against potential disruptions of equipment failures.

In mathematical terms, SC-UC-ACOPF is a challenging large-scale mixed-integer nonlinear optimization model. This means that the decisions involve both discrete variables, e.g. the turning on and off of generators and switching of transmission lines and transformers, and continuous decisions, e.g. the amount of energy generated by each generator and the power flows in the power grid. The physics of the power flow is described by nonlinear equations involving real and reactive power and bus voltages. Another key feature is the large number of contingencies, i.e. the system needs to stay reliable in face of failure of any one equipment, such as transmission lines and generators. The U.S. power grids are extremely complicated and large scale with more than 5,000 generators, 50,000 buses, and 100,000 high-voltage transmission lines, making the SC-UC-ACOPF a very large-scale computation challenge.

The research developed in this project aims to solve the SC-UC-ACOPF problems in the three timescales, i.e. weekly, daily, and every 10-min. The proposed computational methods are built on a principled algorithmic approach of decomposition and penalization. More specifically, the algorithm develops spatial and temporal decomposition by exploiting the strong temporal coupling and weak spatial coupling of the UC problem and the complementary feature, i.e. weak temporal coupling and strong

spatial coupling of the ACOPF problem. The algorithm also leverages recent progresses in strong convex relaxation of ACOPF. A unique feature of the proposed approach is that it generates a valid, global upper bound on the optimal maximum profit. In this way, a global optimality gap is available to measure the quality of the solution.

To further speed up computation, the research team has developed a plethora of effective heuristics to strengthen the iterative penalty-based decomposition framework. For instance, a heuristic is developed to construct inner approximations of the time coupling constraints within the time decoupled problems. Contingencies are pre-screened and low-rank matrix computation is exploited to find the almost unique solution to each contingency. A novel heuristic for line switching is proposed and tested with positive impacts on instances where line switching is beneficial.

Taking a systematic approach and carefully handling every detail of the problem pays off. The TIM-GO's performance throughout the trials and the final event was stellar. TIM-GO garnered the second highest total prize money and is ranked in the top three positions across all categories of comparison.

Acknowledgements

We thank the DOE ARPA-E for creating the Grid Optimization Challenges, which have been instrumental in invigorating the research activities and pushing the research frontier in power system computation and optimization. We are very grateful for their continued financial support to our team. We also acknowledge the GO competition administration team in PNNL for providing technical support and patiently answering our countless questions and for maintaining such a stable and easily accessible testing platform throughout the competition.

Accomplishments and Objectives

Tasks	Milestones and Deliverables
Task 1: Participate in Trial 1	T1: Develop an algorithmic strategy for solving SC-UC-ACOPF We proposed a hierarchical decomposition algorithm for solving the SC-UC-ACOPF, where the upper level uses an alternating penalty method, which decouples UC and ACOPF; and on the lower level, the UC and ACOPF are further decomposed through spatial and temporal decomposition. T2: Develop local testing capability We chose Julia as the programming language based on its superior computation performance and flexibility for prototyping. We developed a preliminary version of the proposed algorithm and tested on MIT's Supercloud as a local replication of the competition's GO platform.

	T3: Participation in Trial 1 Trial 1 took place on Jan 25-27, 2023. Our team ranked the 4th place in scores in Divisions 1, 2, 3, and 4, and the sum scores. We ranked the 2nd in the number of best scenario objectives, and ranked 1st or 2nd in the number of feasible scores in all divisions. We were also noted by the PNNL admin as the only team that heeded the request to not do switching when asked not to.
Task 2: Participate in Trial 2	T4: Develop a convex relaxation scheme for ACOPF used in the iterative penalty method ACOPF is one of the key computational bottlenecks in the iterative penalty approach. To speed up the overall algorithm, we developed a second-order conic relaxation scheme for ACOPF in the penalty framework. This substantially reduced computation time and made it possible to run several iterations of the iterative penalty method, thus improving the accuracy of the solution. T5: Develop an effective approach for handling contingencies The contingency model in Challenge 3 is different from the past two challenges in that the contingencies are modeled with DC power flow, rather than AC power flow. To take advantage of this simpler representation of the power flow, we developed an algorithm to compute the contingency solutions using linear algebra. This makes it very fast to incorporate many contingencies in the problem. T6: Participation in Trial 2 We participated in Trial 2 on April 13-14, 2023. Our team ranked the 4th place in Division 1, the 2nd place in Division 2, the 1st place in Division 3, and the 2nd place in total score. The number of best scores achieved by our approach ranked the 1st place among all teams.
Task 3: Participate in Trial 3	T7: Develop heuristics for handling time coupling constraints We further strengthened the penalty framework by incorporating the time coupling constraints back into the time decoupled ACOPF problems. The heuristics construct convex restrictions (in contrast to convex relaxations) of the ramping constraints and incorporate them into the ACOPF problem in each time period so that the solution of each time period also respects the ramping constraints that link time periods together. T8: Memory management

	We encountered memory challenges in solving the largest instances. To resolve these issues, we developed procedures to carefully manage the memory usage in Julia. T9: Participation in Trial 3 We participated in Trial 3 on June 15-16, 2023. Our team ranked the 3rd place in Division 1, the 6th place in Division 2, the 4th place in Division 3, and the 6th place in total score. We ranked the 3rd in the total number of best scores.
Task 4: Participate in Final Event	T10: Improve computational efficiency of all the heuristics After Trial 3, we further improved computation efficiencies of all the heuristics, including better tuning the logic for determining the overall number of iterations of the penalty methods, the memory management to improve code stability, and a heuristics for line switching. T11: Participation in Final Event We participated in the Final Event on Aug 31-Sept 4, 2023 and ranked the 3rd in Division 1, the 2nd in Division 2, the 1st in Division 3, and the 3rd in the total number of best scores.

Project Outputs

Paper:

1. A spatial and temporal decomposition penalization framework for solving large-scale UC-AC OPF. Andy Sun. Working paper, 2024.