



Coordination Mechanisms for Seamless Operation of Interconnected Power Systems

Final Project Report

M-38

Power Systems Engineering Research Center
*Empowering Minds to Engineer
the Future Electric Energy System*



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P SERC Publication 20-05

October 2020

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Acknowledgements

We wish to thank our industry advisors whose help has been invaluable to the project. Our advisors include Jim Price (CAISO), Yohan Sutjandra (TEA), Anupam Thatte (MISO), Harvey Scribner (SPP), Jay Caspary (SPP), M.Gary Helm (PJM), Jianzhong Tong (PJM), Khosrow Moslehi (ABB), Mirrasoul Mousavi (ABB), Feng Zhao (ISO-NE), Tongxin Zheng (ISO-NE), Di Shi (GEIRI N. America), Qin Wang (EPRI), Erik Ela (EPRI), Nikita Singhal (EPRI), Evangelos Farantatos (EPRI), Miguel Ortega-Vasquez (EPRI).

We also thank Ye Guo (former, Cornell) and Kursat Mestav (Cornell) for their contributions on the project.

Executive Summary

Parts of an interconnected power system are often managed by different independent system operators (ISOs). Each ISO operates wholesale electricity markets within its footprint (henceforth called an area). This project focuses on coordination mechanisms to increase the benefits of interchange among the players in wholesale markets of multiple areas that are connected via tie lines. Specifically, this final report analyzes the existing coordination mechanisms, offers algorithmic innovations to enable such mechanisms, and suggests systematic modifications to improve these mechanisms.

Why is coordination among areas important? Tie lines that interconnect different areas often have adequate transfer capabilities to cover a significant portion of the electricity demand in each area. However, tie lines are often underutilized or not used in an economically efficient manner. Power flows scheduled over tie lines often occur from an area with higher prices to an area with lower prices. Also, tie line schedules often fail to eliminate price differences between border buses of interconnected areas. Such schedules lead to large economic losses. For example, losses due to lack of coordination between ISO-NE and NYISO have been estimated to be \$784 million from 2006 to 2010, according to White and Pike in their 2011 report. Effective coordination among ISOs may lead to significant cost savings. Indeed, the final report of this project provides significant tools to allow ISOs to meet such goals.

Clearly, these inefficiencies in tie-line scheduling can be largely eliminated by the integration of market operations in different areas. However, such a fusion remains untenable in the near future, given the significant regulatory and legal structures of the wholesale markets that have separately developed in the different areas over more than two decades. Absent the possibility of an integrated market, the burden falls on coordination mechanisms to remove, or at least, minimize economic inefficiencies in scheduling power flows over tie lines. This project proposes schemes to improve coordination based on the insights obtained from the economic analysis of the main causes of inefficiencies and prescribes methods to efficiently overcome these limitations.

ISOs and market monitors have long recognized the need for comprehensive restructuring of tie-line scheduling processes. Early research efforts sought algorithmic frameworks that allow ISOs of interconnected neighboring areas to compute a tie-line schedule that forms a part of a jointly optimal dispatch in a distributed fashion. The distributed nature of the algorithm seeks to obtain convergence to a jointly optimal dispatch in an iterative fashion without necessarily sharing all information from one area with the other. These efforts under the title of “Tie Optimization” (TO), however, were never realized in practice. Such a mechanism was perceived as one ISO taking a financial position in the other’s markets, running counter to the financial neutrality of the ISOs. Such a mechanism also defined too far a departure from the earlier market-based, albeit inefficient, mechanism to determine tie-line flows. Multiple pairs of ISOs ultimately adopted a different market-based mechanism called “Coordinated Transaction Scheduling” (CTS) that even received approval by FERC. This project analyzes the main sources of inefficiencies in CTS, suggests both market innovations and algorithmic tools to tackle these inefficiencies. Specifically, the research identifies inefficiencies due to limited trading locations for CTS, market liquidity and strategic interaction of market participants, as well as those emanating from the sources of uncertainty in demand and supply conditions at the time of scheduling.

This report includes the results of efforts in three distinct thrusts:

A. Game-theoretic analysis of CTS markets—equilibrium and learning. The CTS mechanism involves market participants that compete to transport power from one area to the other. The obligation on the bidders is purely financial in that they are not responsible for the physical delivery of power, even though their bids define the tie-line schedule and they are paid based on the realized price spread between the proxy buses of neighboring areas. Naturally, the efficiency of the CTS market critically depends on the strategic interaction among the market participants. This work analyzes how the strategic incentives of market participants may be aligned with market efficiency. The analysis reveals several important insights. First, lack of liquidity has a strong impact on CTS market efficiency. Second, ISOs' forecasts of realized price spread play a key role in the CTS market outcomes. CTS bidders have some ability to correct systematic forecast errors by ISOs, but the quality of the forecasts largely dictates the outcomes. Third, transaction fees negatively impact CTS market outcome and can further hamper liquidity of the CTS market over the long run. The results from the game theoretic analysis are corroborated by simulation results obtained under the condition that bidders learn to bid in a realistic market environment.

B. Algorithms for tie-line scheduling under uncertainty. Tie-line schedules are always determined with a lead-time to power delivery, leading to uncertainty in demand and supply conditions during the scheduling process. This work develops a distributed solution architecture for robust tie-line scheduling. The technique draws on multi-parametric linear programming and defines an algorithmic framework to solve large distributed linear programs applicable to tie-line scheduling. The algorithm converges to an optimal tie-line schedule within a few iterations and does not require ISOs to reveal their sensitive information on the dispatch cost structures, the network constraints or the nature of their uncertainty sets to arrive at the optimal solution.

C. Generalized CTS market design to tackle limited trading locations. The CTS mechanism in practice allows bidders to trade power only between two “proxy” bus locations within neighboring areas. As a result, this mechanism does not accurately reflect the physics of the power flows over multiple tie-lines that may exist between two areas. A similar problem arises when three areas are interconnected via tie-lines. To overcome this so-called “loop flow” phenomenon in tie-line scheduling, an easy-to-implement modification of the CTS mechanism is proposed that allows CTS market participants to offer the delivery of power from any border bus in one area to any border bus in a neighboring interconnected area. When the CTS market has a sufficiently large number of bidders, the proposed mechanism is shown to completely correct the loop flow issue.

Project Publications:

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- [2] Y. Ji, T. Zheng, and L. Tong, “Stochastic interchange scheduling in the real-time electricity market”, IEEE Transactions on Power Systems. 32.3, pp. 2017-2027, 2017.
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- [7] M. Ndrio, S. Bose, L. Tong, and Y. Guo, "Coordinated Transaction Scheduling in Multi-Area Power Systems: Equilibrium and Learning," *In preparation*, 2020.

Student Theses:

- [1] Yuting Ji. "Operation under Uncertainty in Electric Grid: A Multiparametric Programming Approach". Ph.D. thesis. Cornell University. January 2017.
- [2] Ogün Yurdakul. "Analysis and Performance Evaluation of Coordinated Transaction Scheduling". M.S. thesis. University of Illinois at Urbana-Champaign. May 2018.
- [3] Mariola Ndrio. "Equilibrium and Learning in Electricity Markets: A Scalar-Parameterized Supply and Demand Function Approach". Ph.D. thesis. University of Illinois at Urbana-Champaign. January 2021.