Study Committee C5

ELECTRICITY MARKETS AND REGULATION

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Implementation of a wholesale electricity market based on bilevel programming algorithm in Cyprus

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Introduction

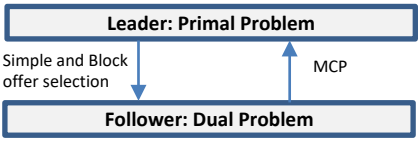
Simple stepwise orders and complex order types such as curtailable and linked profile block orders are allowed in the Cypriot market. Due to the non-convexities introduced by these order types, a market equilibrium supported by uniform price does not exist, which leads to paradoxically accepted and paradoxically rejected block order.

The European electricity market regulation do not allow paradoxically accepted orders; therefore, the Market Clearing Price (MCP) shall be incorporated into the market clearing algorithm. European coupled electricity market use an iterative algorithm called EUPHEMIA, which eliminates the out-of-money block orders from the solution at each consecutive iteration.

Taking advantage of several unique characteristics of Cyprus such as its isolated geographical location which results in a single bidding zone without interconnections, and the small number of Market Participants, a bilevel programming modelling approach has been selected for the implementation of the Day-Ahead electricity market, capable of providing one-shot optimal solutions respecting the uniform price condition.

Bilevel Optimization Based Market Clearing Algorithm

The proposed algorithm is based on a "primal-dual" bilevel programming model, where the dual of the primal welfare optimization problem is the lower-level problem in the bilevel model. The latter provides the market clearing price that is explicitly incorporated in the primal problem as an optimization variable to avoid selecting the out-of-money blocks orders, the so-called Paradoxically Accepted Blocks.



Given that the dual problem is linear and convex, the following steps are followed to merge the bilevel problem containing the primal and the dual problem into a single optimization problem containing both continuous and integer variables:

- Write the Karush–Kuhn–Tucker (KKT) conditions for the dual problem
- Complementary slackness conditions from KKT can be replaced by the equality associated with strong duality
- Insert the KKTs and equality associated with strong duality back to primal problem.

The resulting MIP problem can be solved using on-the-shelf optimization solvers such as CPLEX.

Test results

Scenario 1: To validate the foundation of primal-dual formulation; we first executed the algorithm in the absence of dual information (MCP). Second, the same scenario is executed with dual information and the block order selection market rules integrated into the overall market clearing problem. The following table provide the results:

Scenario	MIP GAP (%)	Execution Time (Seconds)	Number of PABO	Number of PRBO	Number of Partially Cleared BO	Average MCP (€/MWh)
No dual information	0.01	0.72	8	0	0	95.39
Full bilevel model	0.02	2.36	0	3	1	97.00

Scenario 2: The impact of increasing RES generation on the market prices is analyzed in this scenario:

Conclusion

- Utilizing the theoretical properties of bilevel programming and applying linearization, the paper has demonstrated that the algorithm can handle the day-ahead clearing of a small-size real-world market in a transparent and robust manner, based on realistic test cases from the Cyprus power market.
- The unique characteristic of this modeling approach is the avoidance of the iterative procedure used in EUPHEMIA, while successfully handling the Paradoxically Accepted Orders condition.