Stochastic optimization under price uncertainty in auction-based electricity markets – Case study of a virtual power plant marketing its flexibilities in the German spot markets

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Overview

The integrated provision of energy among various energy sectors plays an important role in the process of the implementation of decarbonisation of large energy systems. An important pillar of energy system-wide decarbonisation strategies therefore is decarbonisation of the heat sector, where nowadays still a large percentage of heat supply originates from high-emission fossil fuels like coal or petroleum.

In Central Europe, Combined Heat and Power (CHP) plant applications, e.g. in local district heating networks, represent established methods to provide both electricity and heat at the same time, lowering overall fuel demands and lowering concomitant emissions. However, the optimal marketing and production scheduling of the heat and power-providing portfolios under price uncertainty is a challenging and often complex task. The importance of proper uncertainty handling is underscored even more if the optimal dispatch of flexible technologies like storages needs to be considered.

In this paper, we propose an enhanced multi-stage stochastic programming model that is based on an approach of Thorin, Brand and Weber (2005) and Kempgens (2018), and further extend it for coordinated bidding in two sequential markets, namely the one-hour and fifteen-minute electricity products in the German (day-ahead) spot market.

Our study develops and applies a stochastic mixed-integer linear programming model for a virtual power plant, acting as a price taker in the mentioned electricity markets. The model determines the optimal bidding strategies for a heterogeneous portfolio of small motor-CHP units, heat pumps, electric storage heaters and battery storage systems. The main contributions of this paper are:

1. Consideration of two day-ahead market segments, the hourly and quarter-hourly German EPEX Spot auctions. As a side effect, we gain valuable insight into questions of dealing with arbitrage possibilities between those two products partly covering the same period. Especially in the German market design, individual quarter-hours have shown to obtain much higher prices than other quarter-hours of the same hour, or the corresponding hourly electricity product itself.

2. Backtesting the stochastic optimization model with real market data and heat demand profiles and application to a real-world, diversified portfolio, enabling an effort-benefit analysis of the chosen approach.

We find that stochastic optimisation is a valuable optimisation method that may inform and improve individual marketer’s decision-making processes. However, the observable additional benefits, i.e. compared to deterministic point forecasts, are limited in the investigated cases, while increasing computational expensiveness significantly by adding further scenarios.

Methods

We propose a multi-stage stochastic programming model, modelling the hourly and quarter-hourly electricity marketing opportunities as sequential decisions under uncertainty, followed by a deterministic dispatch optimization. Therefore, a test portfolio from a research project, based on real units of a small municipal utility in the German state of North-Rhine Westphalia, is used as a case study.

The optimizations are executed over the horizon of one year, using a rolling-window approach for both price prediction and scenario generation and the optimisation itself. The optimised objective is the expected profit of the portfolio owner, taking into account electricity market revenues, as well as fuel and start-up ramping costs of the respective power plants.

Backtesting is conducted using real heat demand data and price data from October 1, 2016 until September 30, 2017, as well as price data from the previous two years as basis for price scenario generation. The determination of price distributions and unreduced price paths is hereby based on the work of Pape, Vogler, Woll and Weber (2017), applying this method for quarter-hourly, instead of hourly electricity products. The hourly prices are identified as mean values of the four predicted quarter-hourly values in each reduced scenario. For scenario path reduction, a k-means algorithm is applied to the resulting 1000 price simulation paths. We investigate cases with k=17 and k=62 to compare the effects on the objective function values and computation time, comparing them also to the deterministic case (k=1) and perfect foresight during the rolling window. Additionally, we also investigate the effects by introduction and/or elimination of portfolio assets like electricity storages on these results.

Results

Our preliminary results show that our deterministic (one-scenario) forecasts lead to foregone revenues of about 3.5% of the cumulative yearly objective function value compared to perfect foresight. Stochastic optimisation with 17 price scenarios leads to an increase in yearly revenues of less than 1% per year, the further enhancement by raising the number to 62 price scenarios only increases contributions further by less than 0.5%, while computation time is amplified significantly by both adjustments. Additionally, the positive impact of flexible devices like electrical storage in our given setting is also limited, adding less than one percent of additional contribution to the overall portfolio results[1].

Conclusions

The obtained results so far suggest a limited potential of stochastic programming under the chosen approach for the given portfolio, resulting from a high rigidity of heat delivery obligations and limited flexibility within individual local heat networks in the analysed case study. The computational burden of stochastic programming, increasing with the number of scenarios in the stochastic scenario tree, combined with a decreasing marginal contribution to the optimization objective value suggests that a limited number of scenarios is already sufficient to harvest the benefits of stochastic modelling.

Despite the mentioned limitations, stochastic programming represents a valuable optimization method in the context of portfolio modelling. The applicability of mixed-integer stochastic programming to complex portfolios in real-time marketing, as demonstrated in our analysis, however, still requires computational improvements to deal with high numbers of scenarios.

References

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Kempgens (2018): Betrachtung steuernder Ladestrategien für Elektrofahrzeuge sowie Minutenreservevermarktung von Elektrofahrzeugen, PhD Thesis, University of Duisburg-Essen.

Pape, Vogler, Woll and Weber (2017): Forecasting the Distributions of Hourly Electricity Spot Prices – Accounting for Serial Correlation Patterns and Non-Normality of Price Distributions. HEMF Working Paper No. 05/2017.

[1] Further optimisation runs under adjusted portfolio assumptions are still in progress.