EXTENDED BENDERS DECOMPOSITION FOR CVAR-CONSTRAINED UNIT COMMITMENT DECISIONS IN PAN-EUROPEAN ENERGY SYSTEM MODELS CONSIDERING FEED-IN UNCERTAINTIES

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Overview

The energy system decarbonization leads to an increasing relevance of intraday markets to balance forecasting uncertainties from fluctuating renewable energy sources. The evaluation of profit opportunities on the intraday market and the determination of the future demand for flexible power plants by fundamental models is currently limited. Due to computational complexity, fundamental energy system models focus on only two configurations at present. Either technical and economic constraints are modelled in detail, but deterministically, or they are simplified considerably, allowing for uncertainty and partly risk-constrained modelling. In this paper, a novel method enabling the integration of forecasting errors and risk aversion into a pan-European fundamental power plant optimization model is presented to adequately evaluate the business model and the technical market behaviour of power plants in energy systems with a high penetration of renewables. This is realized by nesting of a Lagrangian Relaxation and an extended Benders decomposition. We show that the process converges rapidly and grows only linearly with the number of scenarios considered.

Methods

The model formulation aims at fundamentally modelling the decision process in the day ahead market (DA) by taking into account possible revenues from a yet uncertain subsequent intraday market (ID). The key assumption for the fundamental representation of intraday trading volumes in this paper is to imply that forecasting errors are predominately impacting these volumes [1]. The model therefore considers all relevant techno-economical constraints of each single power plant (above 10 MW) within the European energy system using mixed integer programing approach [2]. Furthermore, the Conditional Value-at-Risk (CVaR) is applied as a risk measure to ensure risk averse decision behaviour [3]. Fundamental energy system models based on unit commtiment approaches – like the one presented hereafter - in general aim at cost minimization, which converges into real market behaviour in markets with uniform pricing [4]. The joint consideration of the DA and the ID market subject to forecasting uncertainties can be represented by a two-stage stochastic linear programming approach [5]. The first stage corresponds to the DA-decision, which is (in this approach) not exposed to uncertainty, while the second stage corresponds to the probability weighted scenarios for the ID-market. To solve this problem efficiently, a Lagrangian Relaxation is applied to relax the load coverage in each market zone, so that each power plant can be optimized decoupled. In addition, a Benders Decomposition is used to split the single power plant problem to further reduce solving complexity. Therefore the common Benders approach, which coordinates the decoupled problem by reducing the solution space by appending constraints, is extened by simulateous adding further columns to the optimization problem to cope with the integration of CVaR [6]. The master problem of the Benders decomposed single unit optimization problem represents a computational bottleneck if solved for more than one iteration. To further speed-up convergence within the extended Benders decomposition scheme, we introduce customized MIP-starts and B&B-cutoffs We show that the the application of Benders is faster, if there are less than four Benders iterations necessary. Therefore, a single power plant problem exceeding this number of iterations is solved in a closed formulation in the subsequent Lagrangian iteration, resulting in a hybrid Benders application. However, only 1.16% of all (in total several thousand) power plants are solved in the closed formulation approach.

Results

The relevance of the corresponding paper's approach is validated by in two criteria – convergence speed and quality of results. First, the suggested formulation has to outperform the closed formulation, because the latter one is not computationably realisable when applied to real-world problems. We show that the suggested formulation improves the solving time by 44% in comparison to the closed solution when using 20 ID-scenarios. In addition, the increase in solving time when using more scenarios increases significantly slower in contrast to the closed formulation.

Furthermore, the RAM requirements also undercut the requirements of the closed solution. The superposed Lagrangian Relaxation converges sufficiently for the DA and the ID-market. Second, the quality of the results – when comparing the power plant behaviour and the resulting prices – is a key aspect for the application of the model for energy system evaluations. The resulting power plant schedules confirm a rational behaviour. In addition the resulting market prices show a realistic magnitude and volatility compared to realized DA and ID-prices in 2014. Figure 1 shows exemplary DA-prices and the corresponding ID-price distribution resulting from the model's application.

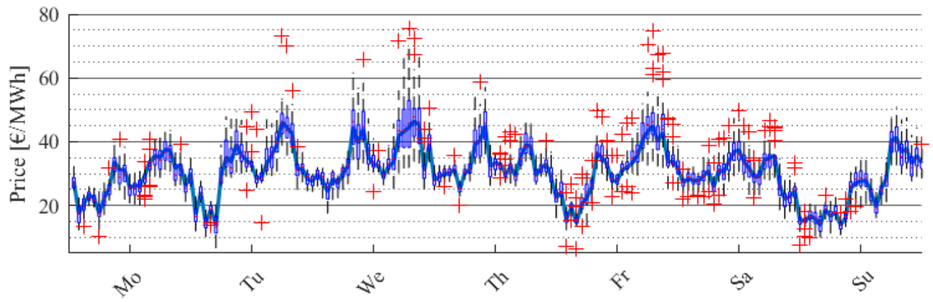

Figure 1: Sample DA price and ID price distributions (25%-75% quantiles represented by boxes; outliers are red crosses) for the second week of January 2014.

Conclusions

In this paper, a stochastic unit commitment approach taking into account forecasting errors of both REN and electrical load is developed. In contrast to the broad range of classical fundamental electricity market models, which only take into account the unit commitment for the DA market, the ID market to balance forecasting errors is considered. Due to the immanent price uncertainty in the ID market, the consideration of risk-averse behavior is compulsory in order to depict a more realistic decision behavior. The use of CVaR has proven to be suitable for this purpose. The mixed integer optimization problem formulation, however, grows drastic for each additional ID scenario considered, which leads to a significant increase in computing time. To reduce the complexity when solving this optimization problem, a hybrid solution of the closed approach and a Benders method with multi-cuts extended by column generation is used. In addition, the master problem is significantly accelerated by using MIP-starts and branch-and-bound cut-offs. In application oof the procedure to the DA and the ID market in Germany, taking into account all DA markets in the European integrated network, a plausible and realistic behavior of the model is shown. The presented decomposition approach is currently not capable of considering integer ID variables, since the dual decision variables of the subproblem, which only exist for linear programs, are necessary in the cut generation. Thus it is not possible yet to make decisions regarding a unit's start-up in the ID market. Due to computational limits, the closed approach can not be applied for this case so that further research could focus on integrating approaches capable of generating Benders cuts in integer subproblems could be integrated [7].

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