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Optimal pricing for electricity retailers based on data-driven consumers' price-response

P. 430-464

Authors
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Abstract
In the present work, we tackle the problem of finding the optimal price tariff to be set by a risk-averse electric retailer participating in the pool and whose customers are price sensitive. We assume that the retailer has access to a sufficiently large smart-meter dataset from which it can statistically characterize the relationship between the tariff price and the demand load of its clients. Three different models are analyzed to predict the aggregated load as a function of the electricity prices and other parameters, as humidity or temperature. More specifically, we train linear regression (predictive) models to forecast the resulting demand load as a function of the retail price. Then, we will insert this model in a quadratic optimization problem which evaluates the optimal price to be offered. This optimization problem accounts for different sources of uncertainty including consumer's response, pool prices and renewable source availability, and relies on a stochastic and risk-averse formulation. In particular, one important contribution of this work is to base the scenario generation and reduction procedure on the statistical properties of the resulting predictive model. This allows us to properly quantify (data-driven) not only the expected value but the level of uncertainty associated with the main problem parameters. Moreover, we consider both standard forward-based contracts and the recently introduced power purchase agreement contracts as risk-hedging tools for the retailer. The results are promising as profits are found for the retailer with highly competitive prices and some possible improvements are shown if richer datasets could be available in the future. A realistic case study and multiple sensitivity analyses have been performed to characterize the risk-aversion behavior of the retailer considering price-sensitive consumers. It has been assumed that the energy procurement of the retailer can be satisfied from the pool and different types of contracts. The obtained results reveal that the risk-aversion degree of the retailer strongly influences contracting decisions, whereas the price sensitiveness of consumers has a higher impact on the selling price offered.

Solving certain complementarity problems in power markets via convex programming

P. 465-491

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Abstract
We address the solution of certain Mathematical Programs with Equilibrium Constraints (MPECs) in power markets using convex optimization. These MPECs constitute a class of complementarity problems relevant to the design and operation of power markets. Specifically, given a non-convex continuous MPEC of the considered type, we iteratively solve a collection of convex optimization problems that approximate the MPEC until a pre-specified tolerance is reached. We use an insightful example to illustrate the proposed solution technique and a case study to analyze its computational performance.

Ambiguities and nonmonotonicities under prosumer power P. 492-532

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Abstract

Prosumers adopt distributed energy resources (DER) to cover part of their own consumption and to sell surplus energy. Although individual prosumers are too dispersed to exert operational market power, they may collectively hold a strategic advantage over conventional generation in selecting DER capacity via aggregators. We devise a bilevel model to examine DER capacity sizing by a collective prosumer as a Stackelberg leader in an electricity industry where conventional generation may exert market power in operations. At the upper level, the prosumer chooses DER capacity in anticipation of lower-level operations by conventional generation and DER output. We demonstrate that exertion of market power in operations by conventional generation and the marginal cost of conventional generation affect DER investment by the prosumer in a nonmonotonic manner. Intuitively, in an industry where conventional generation exerts market power in operations similar to a monopoly (MO), the prosumer invests in more DER capacity than under perfectly competitive operations (PC) to take advantage of a high market-clearing price. However, if the marginal cost of conventional generation is high enough, then this intuitive result is reversed as the prosumer adopts more DER capacity under PC than under MO. This is because the high marginal cost of conventional generation prevents the market-clearing price from decreasing, thereby allowing for higher prosumer revenues. Moreover, competition relieves the chokehold on consumption under MO, which further incentivises the prosumer to expand DER capacity to capture market share. We prove the existence of a critical threshold for the marginal cost of conventional generation that leads to this counterintuitive result. Finally, we propose a countervailing regulatory mechanism that yields welfare-enhancing DER investment even in deregulated electricity industries.

Regression markets and application to energy forecasting P. 533-573

Authors

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Abstract

Energy forecasting has attracted enormous attention over the last few decades, with novel proposals related to the use of heterogeneous data sources, probabilistic forecasting, online learning, etc. A key aspect that emerged is that learning and forecasting may highly benefit from distributed data, though not only in the geographical sense. That is, various agents collect and own data that may be useful to others. In contrast to recent proposals that look into distributed and privacy-preserving learning (incentive-free), we explore here a framework called regression markets. There, agents aiming to improve their forecasts post a regression task, for which other agents may contribute by sharing their data for their features and get monetarily rewarded for it. The market design is for regression models that are linear in their parameters, and possibly separable, with estimation performed based on either batch or online learning. Both in-sample and out-of-sample aspects are considered, with markets for fitting models in-sample, and then for improving genuine forecasts out-of-sample. Such regression markets rely on recent concepts within interpretability of machine learning approaches and cooperative game theory, with Shapley additive explanations. Besides introducing the market design and proving its desirable properties, application results are shown based on simulation studies (to highlight the salient features of the proposal) and with real-world case studies.

The impact of convexity on expansion planning in low-carbon electricity markets P. 574–593

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Abstract

Expansion planning models are tools frequently employed to analyze the transition to a carbon-neutral power system. Such models provide estimates for an optimal technology mix and optimal operating decisions, but they are also often used to obtain prices and subsequently calculate profits. This paper analyzes the impact of modeling assumptions on convexity for power system outcomes and, in particular, on investment cost recovery. Through a case study, we find that although there is a long-term equilibrium for producers under convex models, introducing realistic constraints, such as non-convexities/lumpiness of investments, inelastic demand or unit commitment constraints, leads to profitability challenges. We furthermore demonstrate that considering only short-term marginal costs in market-clearing may potentially create a significant missing-money problem caused by a missing-market problem and dual degeneracy in a 100 percent renewable system.

Abstract

To manage renewable generation and load consumption uncertainty, chance-constrained optimal power flow (OPF) formulations have been proposed. However, conventional solution approaches often rely on accurate estimates of uncertainty distributions, which are rarely available in reality. When the distributions are not known but can be limited to a set of plausible candidates, termed an ambiguity set, distributionally robust (DR) optimization can reduce out-of-sample violation of chance constraints. Nevertheless, a DR model may yield conservative solutions if the ambiguity set is too large. In view that most practical uncertainty distributions for renewable generation are unimodal, in this paper, we integrate unimodality into a moment-based ambiguity set to reduce the conservatism of a DR-OPF model. We review exact reformulations, approximations, and an online algorithm for solving this model. We extend these results to derive a new, offline solution algorithm. Specifically, this algorithm uses a parameter selection approach that searches for an optimal approximation of the DR-OPF model before solving it. This significantly improves the computational efficiency and solution quality. We evaluate the performance of the offline algorithm against existing solution approaches for DR-OPF using modified IEEE 118-bus and 300-bus systems with high penetrations of renewable generation. Results show that including unimodality reduces solution conservatism and cost without degrading reliability significantly.

Abstract

The optimal design of pipeline networks has inspired process systems engineers and operations research practitioners since the earliest times of mathematical programming. The nonlinear equations governing pressure drops, energy consumption and capital investments have motivated nonlinear programming (NLP) approaches and solution techniques, as well as mixed-integer nonlinear programming (MINLP) formulations and decomposition strategies. In this overview paper, we present a systematic description of the mathematical models proposed in recent years for the optimal design of pipeline networks in the energy industry. We provide a general framework to address these problems based on both the topology of the network to build, and the physical properties of the fluids to transport. We illustrate the computational challenges through several examples from industry collaboration projects, published in recent papers from our research group.

Abstract

Many optimization problems involve uncertain parameters which, if not appropriately accounted for, can cause solution infeasiblity. In this work, we consider joint chance-constrained optimization problems, which require all constraints to hold with a given probability, and a two-step solution method based on iterative tuning. Previous work established an a priori feasibility guarantee for this tuning approach, which relies on an assumption that must be verified on a case-by-case basis. In this paper, we propose an empirical methodology using statistical hypothesis testing to assess the validity of this assumption, thus providing further insight into the validity of the a priori guarantee. In addition, we provide sample complexity results to assess the requisite amount of data for the tuning method. We find that for large scale optimization problems, the tuning approach may require significantly less samples than the scenario approach.

We numerically assess these results via application to the optimal power flow problem as well as further assess the scalability of the method and the optimality and feasibility of solutions obtained from tuning.

Day-ahead market bidding taking the balancing power market into account p. 683-703

Authors (first, second and last of 4)
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Abstract

Generation companies with controllable units put considerable analysis into the process of bidding into the day-ahead markets for electricity. This article investigates the gain of coordinating price-taking bids to the day-ahead electricity market (DA) and sequentially cleared energy-only markets, such as the Nordic balancing market (BM). A technically detailed case study from the Nordic market is presented. We find that coordinated bidding is hardly worthwhile under current market conditions, but that only a modest increase in the demand for balancing energy will make coordination profitable. If the supply curve for balancing energy is convex, so that the cost of balancing energy is asymmetric, the gains will be even higher. Finally, we find that day-ahead market bid curves that result from coordinated instances provide extra supply at low prices, and lower supply at high prices, compared to sequential bids. This is rational given the anticipated opportunities that the balancing market offers; however, it makes day-ahead bidding appear to exploit market power.