Evaluating the Cost of Line Capacity Limitations in Aggregations of Commercial Buildings

The trend towards electrification of the heating sector in many cases leads to the replacement of fossil-fueled heating systems with electric heat pumps. This may result to significantly higher consumption and potentially violations of the distribution grid operational limits. We propose a day-ahead optimization strategy to assess the cost of imposing capacity limitations in the total consumption of individual buildings, as well as aggregations of buildings. We show that such capacity limitations lead to an increase for the buildings operational costs, which can be interpreted as the value of these limitations. Based on such calculations, the aggregator can value capacity-limitation services to the distribution system operator. Moreover, the value of aggregation is also highlighted, since it leads to lower costs than imposing the same total capacity limitation on individual buildings.

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Exploiting Flexibility in Coupled Electricity and Natural Gas Markets: A Price-Based Approach

Natural gas-fired power plants (NGFPPs) are considered a highly flexible component of the energy system and can facilitate the large-scale integration of intermittent renewable generation. Therefore, it is necessary to improve the coordination between electric power and natural gas systems. Considering a market-based coupling of these systems, we introduce a decision support tool that increases market efficiency in the current setup where day-ahead and balancing markets are cleared sequentially. The proposed approach relies on the optimal adjustment of natural gas price to modify the scheduling of power plants and reveals the necessary flexibility to handle stochastic renewable production. An essential property of this price-based approach is that it guarantees no financial imbalance (deficit or surplus) for the system operator at the day-ahead stage. Our analysis shows that the proposed mechanism reduces the expected system cost and efficiently accommodates high shares of renewables.

General information
Impact of Public Aggregate Wind Forecasts on Electricity Market Outcomes

Following a call to foster a transparent and more competitive market, member states of the European transmission system operator are required to publish, among other information, aggregate wind power forecasts. The publication of the latter information is expected to benefit market participants by offering better knowledge of the market operation, leading subsequently to a more competitive energy market. Driven by the above regulation, we consider an equilibrium study to address how public information of aggregate wind power forecasts can potentially affect market results, social welfare as well as the profits of participating power producers. We investigate, therefore, a joint day-ahead energy and reserve auction, where producers offer their conventional power strategically based on a complementarity approach and their wind power at generation cost based on a forecast. In parallel, an iterative game-theoretic approach (diagonalization) is incorporated in order to investigate the existence of an equilibrium for various values of aggregate forecast. As anticipated, variations in public forecasts will affect market results and, more precisely, under-forecasts can mislead power producers to make decisions that favor social welfare, while over-forecasts will cause the opposite effect. Furthermore, energy and reserve market prices can also be affected by deviations in aggregate wind forecasts altering, inevitably, the profits of all power producers.
Price-Taker Offering Strategy in Electricity Pay-as-Bid Markets

The recent increase in the deployment of renewable energy sources may affect the offering strategy of conventional producers, mainly in the balancing market. The topics of optimal offering strategy and self-scheduling of thermal units have been extensively addressed in the literature. The feasible operating region of such units can be modeled using a mixed-integer linear programming approach, and the trading problem as a linear programming problem. However, the existing models mostly assume a uniform pricing scheme in all market stages, while several European balancing markets (e.g., in Germany and Italy) are settled under a pay-as-bid pricing scheme. The existing tools for solving the trading problem in pay-as-bid electricity markets rely on non-linear optimization models, which, combined with the unit commitment constraints, result in a mixed-integer non-linear optimization problem. In contrast, we provide a linear formulation for that trading problem. Then, we extend the proposed approach by formulating a two-stage stochastic problem for optimal offering in a two-settlement electricity market with a pay-as-bid pricing scheme at the balancing stage. The resulting model is mixed-integer and linear. The proposed model is tested on a realistic case study against a sequential offering approach, showing the capability of increasing profits in expectation.

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Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electricity markets and energy analytics, Università degli Studi di Padova
Authors: Mazzi, N. (Ekstern), Kazempour, J. (Intern), Pinson, P. (Intern)
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Scopus rating (2014): SJR 2.831 SNIP 3.577 CiteScore 5.31
Transmission expansion in an oligopoly considering generation investment equilibrium

Transmission expansion planning (TEP) is a sophisticated decision-making problem, especially in an oligopolistic electricity market in which a number of strategic (price-maker) producers compete together. A transmission system planner, who is in charge of making TEP decisions, requires considering the future generation investment actions. However, in such an oligopolistic market, each producer makes its own strategic generation investment decisions. This motivates the transmission system planner to consider the generation investment decision-making problem of all producers within its TEP model. The strategic generation investment problem of each producer can be represented by a complementarity bi-level model. The joint consideration of all bi-level models, one per producer, characterizes the generation investment equilibrium that identifies the future evolution of generation investment in the market. This paper proposes a tri-level TEP decision-making model to be solved by the transmission system planner, whose objective is to maximize the social welfare of the market minus the expansion costs, and whose constraints are the transmission expansion limits as well as the generation investment equilibrium problem. This model is then recast as a mixed-integer linear programming problem and solved. Numerical results from an illustrative example and a case study based on the IEEE 14-bus test system demonstrate the usefulness of the proposed approach.

Part one of this two-part paper presents new models for evaluating flexible resources in two-settlement electricity markets (day-ahead and real-time) with uncertain net loads (demand minus wind). Physical resources include wind together with fast- and slow-start demand response and thermal generators. We also model financial participants (virtual bidders). Wind is stochastic, represented by a set of scenarios. The two-settlement system is modeled as a two-stage process in which the first stage involves unit commitment and tentative scheduling, while the second stage adjusts flexible resources to resolve imbalances. The value of various flexible resources is evaluated through four two-settlement models: i) an equilibrium model in which each player independently schedules its generation or purchases to maximize expected profit; ii) a benchmark (expected system cost minimization); iii) a sequential equilibrium model in which the independent system operator (ISO) first optimizes against a deterministic wind power forecast; and iv) an extended sequential equilibrium model with self-scheduling by profit-maximizing slow-start generators. A tight convexified unit commitment allows for demonstration of certain equivalencies of the four models. We show how virtual bidding enhances market performance, since, together with self-scheduling by slow-start generators, it can help a deterministic day-ahead market to choose the most efficient unit commitment.

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Authors: Kazempour, J. (Intern), Hobbs, B. F. (Ekstern)
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Web of Science (2014): Indexed yes
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Scopus rating (2010): SJR 1.949 SNIP 2.826
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BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.94 SNIP 2.723
In Part II of this paper, we present formulations for three two-settlement market models: baseline cost-minimization (Stoch-Opt); and two sequential market models in which an independent system operator (ISO) runs real-time (RT) balancing markets after making day-ahead (DA) generating unit commitment decisions based upon deterministic wind forecasts, while virtual bidders arbitrage the two markets (Seq and SeqSS). The latter two models differ in terms of whether some slow-start generators can self-schedule in the DA market while anticipating probabilities of RT prices. Models in Seq and Seq-SS build on components of the two-settlement equilibrium model (Stoch-MP) defined in Part I of this paper [1]. We then provide numerical results for all four models. A simple single-node case illustrates the economic impacts of flexibility, virtual bidding, and self-schedules, and is followed by a larger case study based on the 24-node IEEE reliability test system. Their results confirm that flexible resources, including fast-start generators and demand response, can reduce expected costs in a sequential two-settlement market. In addition, virtual bidders can also improve the functioning of sequential markets. In some circumstances, virtual bidders (together with self-scheduling by slow-start generators) enable deterministic ISO DA markets to obtain the least (expected) cost unit commitments.
**Bidding strategy for an energy storage facility**

This paper studies operation decisions of energy storage facilities in perfectly and imperfectly competitive markets. In a perfectly competitive market, the storage facility is operated to maximize the social welfare. However, in an imperfectly competitive market, the storage facility operates to maximize its profit, while the market operator aims at maximizing the social welfare. In this case, the storage facility adapts its strategic behavior to take advantage of market conditions. To model the imperfectly competitive market, a bi-level optimization model is implemented to present the interactions between the storage facility and the market operator. In an illustrative test system, operation of the storage facility in these two market structures is compared and discussed.

**General information**

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Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electricity markets and energy analytics, University of Calgary
Authors: Nasrolahpour, E. (Ekstern), Zareipour, H. (Ekstern), Rosehart, W. D. (Ekstern), Kazempour, J. (Intern)
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**Effects of Risk Aversion on Market Outcomes: A Stochastic Two-Stage Equilibrium Model**

This paper evaluates how different risk preferences of electricity producers alter the market-clearing outcomes. Toward this goal, we propose a stochastic equilibrium model for electricity markets with two settlements, i.e., day-ahead and balancing, in which a number of conventional and stochastic renewable (e.g., wind power) producers compete. We assume that all producers are price-taking and can be risk-averse, while loads are inelastic to price. Renewable power production is the only source of uncertainty considered. The risk of profit variability of each producer is incorporated into the model using the conditional value-at-risk (CVaR) metric. The proposed equilibrium model consists of several risk-constrained profit maximization problems (one per producer), several curtailment cost minimization problems (one per load), and power balance constraints. Each optimization problem is then replaced by its optimality conditions, resulting in a mixed complementarity problem. Numerical results from a case study based on the IEEE one-area reliability test system are derived and discussed.

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Impacts of ramping inflexibility of conventional generators on strategic operation of energy storage facilities

This paper proposes an approach to assist a pricemaker merchant energy storage facility in making its optimal operation decisions. The facility operates in a pool-based electricity market, where the ramping capability of other resources is limited. Also, wind power resources exist in the system. The merchant facility seeks to maximize its profit through strategic inter-temporal arbitrage decisions, taking advantage of those ramp limitations. The market operator, on the other hand, aims at maximizing the social welfare under wind power generation uncertainty. Thus, a stochastic bi-level optimization model is proposed, taking into account the interactions between the storage facility and the market operator, and the existing market opportunities for the storage facility. The proposed bilevel model is then transformed into a Mathematical Program with Equilibrium Constraints (MPEC) that can be recast as a Mixed-integer Linear Programming (MILP) problem. Different case studies are presented and discussed using a six-bus illustrative example and the IEEE one-area reliability test system to evaluate the performance of the proposed approach.

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Source: PublicationPreSubmission
Investment in Electricity Generation and Transmission: Decision Making Under Uncertainty

This book provides an in-depth analysis of investment problems pertaining to electric energy infrastructure, including both generation and transmission facilities. The analysis encompasses decision-making tools for expansion planning, reinforcement, and the selection and timing of investment options. In this regard, the book provides an up-to-date description of analytical tools to address challenging investment questions such as:

- How can we expand and/or reinforce our aging electricity transmission infrastructure?
- How can we expand the transmission network of a given region to integrate significant amounts of renewable generation?
- How can we expand generation facilities to achieve a low-carbon electricity production system?
- How can we expand the generation system while ensuring appropriate levels of flexibility to accommodate both demand-related and production-related uncertainties?
- How can we choose among alternative production facilities?
- What is the right time to invest in a given production or transmission facility?

Written in a tutorial style and modular format, the book includes a wealth of illustrative examples to facilitate comprehension. It is intended for advanced undergraduate and graduate students in the fields of electric energy systems, operations research, management science, and economics. Practitioners in the electric energy sector will also benefit from the concepts and techniques presented here.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electricity markets and energy analytics, University of Castilla–La Mancha, University College London
Authors: Conejo, A. J. (Ekstern), Baringo, L. (Ekstern), Kazempour, J. (Intern), Siddiqui, A. S. (Ekstern)
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Sharing wind power forecasts in electricity markets: A numerical analysis

In an electricity pool with significant share of wind power, all generators including conventional and wind power units are generally scheduled in a day-ahead market based on wind power forecasts. Then, a real-time market is cleared given the updated wind power forecast and fixed day-ahead decisions to adjust power imbalances. This sequential market-clearing process may cope with serious operational challenges such as severe power shortage in real-time due to erroneous wind power forecasts in day-ahead market. To overcome such situations, several solutions can be considered such as adding flexible resources to the system. In this paper, we address another potential solution based on information sharing in which market players share their own wind power forecasts with others in day-ahead market. This solution may improve the functioning of sequential market-clearing process through making more informed day-ahead schedules, which reduces the need for balancing resources in real-time operation. This paper numerically evaluates the potential value of sharing forecasts for the whole system in terms of system cost reduction. Besides, its impact on each market player’s profit is analyzed. The framework of this study is based on a stochastic two-stage market setup and complementarity modeling, which allows us to gain further insights into information sharing impacts.

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Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electricity markets and energy analytics, Centre for IT-Intelligent Energy Systems in Cities, University of Mons
Authors: Exizidis, L. (Ekstern), Pinson, P. (Intern), Kazempour, J. (Intern), de Greve, Z. (Ekstern), Vallée, F. (Ekstern)
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Strategic Demand-Side Response to Wind Power Integration
This paper explores the effects of allowing large, price-responsive consumers to provide reserves in a power system with significant penetration of wind energy. A bilevel optimization model represents the utility maximization problem of a large consumer, subject to a stochastic day-ahead co-optimization of energy and reserves that a system operator would solve to clear the market while considering wind power uncertainty. An examination of the market outcomes from both an illustrative and a large-scale study using this model allows analysis of a) the effects of the type of behavior of the large consumer (i.e., strategic vs competitive), b) limits on the amount of reserves it is allowed to provide, and c) variability and accuracy of characterization of wind power uncertainty.

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Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electricity markets and energy analytics, Duke University, Ohio State University
Authors: Daraeepour, A. (Ekstern), Kazempour, S. (Intern), Patiño-Echeverri, D. (Ekstern), Conejo, A. J. (Ekstern)
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Strategic sizing of energy storage facilities in electricity markets

This paper proposes a model to determine the optimasize of an energy storage facility from a strategic investor's perspective. This investor seeks to maximize its profit through making strategic planning, i.e., storage sizing, and strategic operational, i.e., offering and bidding, decisions. We consider the uncertainties associated with rival generators' offering strategies and future load levels in the proposed model. The strategic investment decisions include the sizes of charging device, discharging device and energy reservoir. The proposed model is a stochastic bi-level optimization problem; the planning and operation decisions are made in the upper-level, and market clearing is modeled in the lower-level under different operating scenarios. To make the proposed model computationally tractable, an iterative solution technique based on Benders' decomposition is implemented. This provides a master problem and a set of subproblems for each scenario. Each subproblem is recast as an Mathematical Programs with Equilibrium Constraints (MPEC). Numerical results based on real-life market data from Alberta’s electricity market are provided.
Strategic wind power trading considering rival wind power production

In an electricity market with high share of wind power, it is expected that wind power producers may exercise market power. However, wind producers have to cope with wind’s uncertain nature in order to optimally offer their generation, whereas in a market with more than one wind producers, uncertainty of rival wind power generation should also be considered. Under this context, this paper addresses the impact of rival wind producers on the offering strategy and profits of a pricemaker wind producer. A stochastic day-ahead market setup is considered, which optimizes the day-ahead schedules considering a number of foreseen real-time scenarios. The results indicate that strategic wind producer is more likely to exercise market power having a mid-mean or low-mean forecast distribution, rather than having a high-mean one. Furthermore, it is observed that its offering strategy varies considerably depending on the rival’s wind generation, given that its own expected generation is not high. Finally, as anticipated, expected system cost is higher when both wind power producers are expected to have low wind power generation.

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Investment in conventional and renewable generating units

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Network-constrained AC unit commitment under uncertainty: A Benders’ decomposition approach

This paper proposes an efficient solution approach based on Benders’ decomposition to solve a network-constrained ac unit commitment problem under uncertainty. The wind power production is the only source of uncertainty considered in this paper, which is modeled through a suitable set of scenarios. The proposed model is formulated as a two-stage stochastic programming problem, whose first-stage refers to the day-ahead market, and whose second-stage represents real-time operation. The proposed Benders’ approach allows decomposing the original problem, which is mixed-integer nonlinear and generally intractable, into a mixed-integer linear master problem and a set of nonlinear, but continuous subproblems, one per scenario. In addition, to temporally decompose the proposed ac unit commitment problem, a heuristic technique is used to relax the inter-temporal ramping constraints of the generating units. Numerical results from a case study based on the IEEE one-area reliability test system (RTS) demonstrate the usefulness of the proposed approach.
Strategic Bidding for a Large Consumer

The smart grid technology enables an increasing level of responsiveness on the demand side, facilitating demand serving entities-large consumers and retailers-to procure their electricity needs under the best conditions. Such entities generally exhibit a proactive role in the pool, seeking to procure their energy needs at minimum cost. Within this framework, we propose a mathematical model to help large consumers to derive bidding strategies to alter pool prices to their own benefit. Representing the uncertainty involved, we develop a stochastic complementarity model to derive bidding curves, and show the advantages of such bidding scheme with respect to non-strategic ones.

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Organisations: Ohio State University, Universidad Carlos III de Madrid, Johns Hopkins University
Authors: Kazempour, J. (Intern), Conejo, A. J. (Ekstern), Ruiz, C. (Ekstern)
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Equilibria in an oligopolistic market with wind power production

This paper proposes an approach for analyzing the impacts of large-scale wind power integration on electricity market equilibria. A pool-based oligopolistic electricity market is considered including a day-ahead market and a number of real-time markets. Wind power is considered within the generation portfolio of the strategic producers, and the uncertainty of wind power production is modeled through a set of plausible scenarios. The strategic behavior of each producer is modeled through a stochastic bilevel model. The resulting nonlinear equilibrium problem with equilibrium constraints (EPEC) is linearized and then solved. Numerical results for a test case with increasing levels of the wind power penetration is provided. © 2013 IEEE.

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State: Published
Organisations: University of Calgary, Johns Hopkins University
Authors: Kazempour, J. (Intern), Zareipour, H. (Ekstern)
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Publication information
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ISSN (Print): 0885-8950
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  Web of Science (2017): Indexed Yes
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  Scopus rating (2016): CiteScore 8.17 SJR 3.757 SNIP 3.624
  Web of Science (2016): Indexed yes
  BFI (2015): BFI-level 2
  Scopus rating (2015): SJR 3.602 SNIP 3.486 CiteScore 6.6
  Web of Science (2015): Indexed yes
  BFI (2014): BFI-level 2
  Scopus rating (2014): SJR 2.831 SNIP 3.577 CiteScore 5.31
  Web of Science (2014): Indexed yes
  BFI (2013): BFI-level 2
  Scopus rating (2013): SJR 2.939 SNIP 4.35 CiteScore 6.33
  ISI indexed (2013): ISI indexed yes
  Web of Science (2013): Indexed yes
  BFI (2012): BFI-level 2
  Scopus rating (2012): SJR 2.177 SNIP 3.516 CiteScore 5.84
  ISI indexed (2012): ISI indexed yes
  Web of Science (2012): Indexed yes
  BFI (2011): BFI-level 2
  Scopus rating (2011): SJR 1.725 SNIP 3.254 CiteScore 5.34
  ISI indexed (2011): ISI indexed yes
  Web of Science (2011): Indexed yes
  BFI (2010): BFI-level 2
  Scopus rating (2010): SJR 1.949 SNIP 2.826
  Web of Science (2010): Indexed yes
  BFI (2009): BFI-level 2
  Scopus rating (2009): SJR 1.94 SNIP 2.723
  Web of Science (2009): Indexed yes
  BFI (2008): BFI-level 2
  Scopus rating (2008): SJR 1.537 SNIP 2.448
Minimizing Wind Power Spillage Using an OPF With FACTS Devices

This paper proposes an optimal power flow (OPF) model with flexible AC transmission system (FACTS) devices to minimize wind power spillage. The uncertain wind power production is modeled through a set of scenarios. Once the balancing market is cleared, and the final values of active power productions and consumptions are assigned, the proposed model is used by the system operator to determine optimal reactive power outputs of generating units, voltage magnitude and angles of buses, deployed reserves, and optimal setting of FACTS devices. This system operator tool is formulated as a two-stage stochastic programming model, whose first-stage describes decisions prior to uncertainty realization, and whose second-stage represents the operating conditions involving wind scenarios. Numerical results from a case study based on the IEEE RTS demonstrate the usefulness of the proposed tool.

General information
State: Published
Organisations: KTH - Royal Institute of Technology, Universidad de Castilla-La Mancha, Johns Hopkins University
Authors: Nasri, A. (Ekstern), Conejo, A. J. (Ekstern), Kazempour, J. (Intern), Ghandhari, M. (Ekstern)
Number of pages: 10
Pages: 2150-2159
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Publication information
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Ratings:
BFI (2017): BFI-level 2
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 8.17 SJR 3.757 SNIP 3.624
Web of Science (2016): Indexed Yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 3.602 SNIP 3.486 CiteScore 6.6
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 2.831 SNIP 3.577 CiteScore 5.31
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 2.939 SNIP 4.35 CiteScore 6.33
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 2.177 SNIP 3.516 CiteScore 5.84
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 1.725 SNIP 3.254 CiteScore 5.34
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.949 SNIP 2.826
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.94 SNIP 2.723
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 1.537 SNIP 2.448
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 1.242 SNIP 2.521
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 1.233 SNIP 2.316
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 1.582 SNIP 2.547
Scopus rating (2004): SJR 1.036 SNIP 2.843
Scopus rating (2003): SJR 2.669 SNIP 2.652
Scopus rating (2002): SJR 2.271 SNIP 2.337
Scopus rating (2001): SJR 1.708 SNIP 1.837
Scopus rating (2000): SJR 1.169 SNIP 3.37
Scopus rating (1999): SJR 0.418 SNIP 1.408

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Electrical and Electronic Engineering, Energy Engineering and Power Technology, FACTS devices, optimal power flow (OPF), stochastic programming, thyristor controlled series capacitor (TCSC), wind power spillage, Acoustic generators, Electric load flow, Power electronics, Stochastic programming, Wind power, Facts devices, Flexible ac transmission system (FACTS), Operating condition, Optimal power flows, Optimal reactive power, Thyristor controlled series capacitor, Two-stage stochastic programming, Wind power production, Flexible AC transmission systems, wind power plants, flexible AC transmission systems, load flow, power consumption, power markets, power system simulation, reactive power , IEEE RTS, wind power spillage minimization, FACTS device, optimal power flow model, OPF model, flexible AC transmission system device, wind power production uncertainty modeling, balancing market, optimal reactive power output , voltage magnitude, bus angle, two-stage stochastic programming model, second-stage representation, Wind power generation, Production, Reactive power, Uncertainty, Thyristors, Power transmission lines, Power capacitors, ENGINEERING, OPTIMAL LOCATION, PENETRATION, INTEGRATION, SYSTEMS, Wind power plants, a.c. transmission, Power system management, operation and economics, Optimisation techniques

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Source: Findlt
Source-ID: 261086707
Publication: Research - peer-review › Journal article – Annual report year: 2014
Generation Investment Equilibria With Strategic Producers-Part I: Formulation

The first of this two-paper series proposes a methodology to characterize generation investment equilibria in a pool-based network-constrained electricity market, where the producers behave strategically. To this end, the investment problem of each strategic producer is represented using a bilevel model, whose upper-level problem determines the optimal investment and the supply offering curves to maximize its profit, and whose several lower-level problems represent different market clearing scenarios. This model is transformed into a mathematical program with equilibrium constraint (MPEC) through replacing the lower-level problems by their optimality conditions. The joint consideration of all producer MPECs, one per producer, constitutes an equilibrium problem with equilibrium constraints (EPEC). To identify the solutions of this EPEC, each MPEC problem is replaced by its Karush-Kuhn-Tucker (KKT) conditions, which are in turn linearized. The resulting mixed-integer linear system of equalities and inequalities allows determining the EPEC equilibria through an auxiliary MILP problem.

General information
State: Published
Organisations: Universidad de Castilla-La Mancha, Ecole Centrale de Paris
Authors: Kazempour, J. (Intern), Conejo, A. J. (Ekstern), Ruiz, C. (Ekstern)
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BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 8.17 SJR 3.757 SNIP 3.624
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 3.602 SNIP 3.486 CiteScore 6.6
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 2.831 SNIP 3.577 CiteScore 5.31
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 2.939 SNIP 4.35 CiteScore 6.33
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 2.177 SNIP 3.516 CiteScore 5.84
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 1.725 SNIP 3.254 CiteScore 5.34
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.949 SNIP 2.826
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.94 SNIP 2.723
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 1.537 SNIP 2.448
Web of Science (2008): Indexed yes
This paper analyzes numerically the approach reported in the companion paper for identifying generation investment equilibria in an electricity market where the producers behave strategically. To this end, a two-node illustrative example and a large-scale case study based on the IEEE reliability test system (RTS) are examined and the results obtained are reported and discussed.

**General information**

State: Published
Organisations: Universidad de Castilla-La Mancha
Authors: Kazempour, J. (Intern), Conejo, A. J. (Ekstern), Ruiz, C. (Ekstern)
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- Web of Science (2016): Indexed yes
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- Scopus rating (2015): SJR 3.602 SNIP 3.486 CiteScore 6.6
- Web of Science (2015): Indexed yes
- BFI (2014): BFI-level 2
- Scopus rating (2014): SJR 2.831 SNIP 3.577 CiteScore 5.31
- Web of Science (2014): Indexed yes
Equilibria in futures and spot electricity markets

We describe a model to analyze the equilibrium encompassing an electricity futures market and a number of electricity spot markets sequentially arranged along the time horizon spanned by the futures market. Profit-maximizing strategic electricity producers react to both prices and rival production changes, in both the spot and the futures markets. At each time period, the total demand is considered to depend linearly on the spot price of the considered time period, and the futures market price is assumed to equal the average spot price over the time horizon. Equilibrium conditions at each spot market are described as a function of the futures market decision variables, which in turn allows describing the equilibrium in the futures market implicitly enforcing equilibrium in each spot market. The proposed model allows deriving analytical expressions that characterize such multi-market equilibrium and that can be recast as a mixed linear complementarity problem. This model is useful to gain insight on the outcomes and characteristics of the considered multi-market equilibrium. Such insight may allow the regulator to better design the futures and spot trading floors, their rules and
sequential timing. It may also allow producers to increase the effectiveness of their respective offering strategies. (C) 2011 Elsevier B.V. All rights reserved.
Strategic Generation Investment Considering Futures and Spot Markets

Futures markets are increasingly relevant for trading electric energy as they help to hedge the volatility of the pool prices. In this paper, we analyze the effect of such futures markets on the investment decisions of a strategic electricity producer. To this end, we propose a bilevel model whose upper-level problem represents the investment and offering actions of the producer, and whose multiple lower-level problems represent the clearing of both the futures markets and the pool under different operating conditions. Such model is equivalent to a mathematical program with equilibrium constraints that can be recast as a tractable mixed-integer linear programming problem and that allows assessing the impact of the futures markets on the investment decisions of a strategic producer.

General information
State: Published
Organisations: University of Castilla–La Mancha
Authors: Kazempour, J. (Intern), Conejo, A. J. (Ekstern), Ruiz, C. (Ekstern)
Pages: 1467-1476
Publication date: 2012
Main Research Area: Technical/natural sciences

Publication information
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Volume: 27
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Ratings:
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BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 8.17 SJR 3.757 SNIP 3.624
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 3.602 SNIP 3.486 CiteScore 6.6
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 2.831 SNIP 3.577 CiteScore 5.31
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 2.939 SNIP 4.35 CiteScore 6.33
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 2.177 SNIP 3.516 CiteScore 5.84
ISI indexed (2012): ISI indexed yes
Strategic Generation Investment Under Uncertainty Via Benders Decomposition

We address the generation investment problem faced by a strategic power producer and consider a detailed description of the uncertain parameters involved, namely, rival producer investment and market offering, and demand growth. To identify optimal investment decisions, we consider a target year and propose a bilevel model whose upper-level problem determines investment and offering decisions to maximize expected profit, and whose many lower-level problems represent market clearing conditions per demand block and scenario. Since the producer total expected profit is sufficiently convex with respect to investment decisions, a Benders' decomposition approach is proposed that results in a tractable formulation even if hundred of scenarios are used to describe uncertain parameters. Extensive numerical simulations based on realistic case studies show the good performance of the proposed decomposition approach.
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Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 2.939 SNIP 4.35 CiteScore 6.33
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 2.177 SNIP 3.516 CiteScore 5.84
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 1.725 SNIP 3.254 CiteScore 5.34
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.949 SNIP 2.826
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.94 SNIP 2.723
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 1.537 SNIP 2.448
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 1.242 SNIP 2.521
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 1.233 SNIP 2.316
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 1.582 SNIP 2.547
Scopus rating (2004): SJR 1.036 SNIP 2.843
Scopus rating (2003): SJR 2.669 SNIP 2.652
Scopus rating (2002): SJR 2.271 SNIP 2.337
Scopus rating (2001): SJR 1.708 SNIP 1.837
Scopus rating (2000): SJR 1.169 SNIP 3.37
Scopus rating (1999): SJR 0.418 SNIP 1.408
Original language: English

Electrical and Electronic Engineering, Energy Engineering and Power Technology, Benders' decomposition, generation investment, mathematical programs with equilibrium constraints (MPEC), strategic producer, uncertainty, Benders decomposition, Bilevel, Decomposition approach, Demand growth, Expected profits, Generation investment, Investment decisions, Market clearing, Mathematical programs with equilibrium constraints, Optimal investment decision, Power producer, Uncertain parameters, Profitability, Uncertainty analysis, Investments, power markets, investment, numerical analysis, power generation economics, numerical simulations, strategic generation investment problem, strategic power producer, producer investment, market offering, upper-level problem, lower-level problems, Bender decomposition
Risk-constrained self-scheduling of a fuel and emission constrained power producer using rolling window procedure

This work addresses a relevant methodology for self-scheduling of a price-taker fuel and emission constrained power producer in day-ahead correlated energy, spinning reserve and fuel markets to achieve a trade-off between the expected profit and the risk versus different risk levels based on Markowitz's seminal work in the area of portfolio selection. Here, a set of uncertainties including price forecasting errors and available fuel uncertainty are considered. The latter uncertainty arises because of uncertainties in being called for reserve deployment in the spinning reserve market and availability of power plant. To tackle the price forecasting errors, variances of energy, spinning reserve and fuel prices along with their covariances which are due to markets correlation are taken into account using relevant historical data. In order to tackle available fuel uncertainty, a framework for self-scheduling referred to as rolling window is proposed. This risk-constrained self-scheduling framework is therefore formulated and solved as a mixed-integer non-linear programming problem. Furthermore, numerical results for a case study are discussed. (C) 2010 Elsevier Ltd. All rights reserved.
This paper provides a methodology to assist a strategic producer in making informed decisions on generation investment. A single target year is considered with demand variations modeled through blocks. The strategic behavior of the producer is represented through a bilevel model: the upper-level considers both investment decisions and strategic production actions and the lower-level corresponds to market clearing. Prices are obtained as dual variables of power balance equations. Rival uncertainties (on offering and investment) are characterized through scenarios. The resulting model is a large-scale mixed-integer LP problem solvable using currently available branch-and-cut techniques. Results pertaining to an illustrative example and a case study are reported and discussed.

**General information**

**State:** Published  
**Organisations:** University of Castilla–La Mancha  
**Authors:** Kazempour, J. (Intern), Conejo, A. J. (Ekstern), Ruiz, C. (Ekstern)  
**Number of pages:** 9  
**Pages:** 940-948  
**Publication date:** 2011  
**Main Research Area:** Technical/natural sciences

**Publication information**

**Journal:** IEEE Transactions on Power Systems  
**Volume:** 26
Electrical and Electronic Engineering, Energy Engineering and Power Technology, Generation investment, mathematical program with equilibrium constraints (MPEC), strategic producer, uncertainty, Bilevel, Branch-and-cut techniques, Demand variations, Illustrative examples, Informed decision, Investment decisions, Market clearing, Mathematical program with equilibrium constraints, Mixed-integer, Power balance equations, Strategic Behavior, Investments, power markets, integer programming, investment, linear programming, branch-and-cut techniques, strategic generation investment, investment decisions, market clearing, power balance equations, rival uncertainties, large-scale mixed-integer LP problem, Mathematical model, Production, Uncertainty, Planning, Stochastic processes, Optimization, ENGINEERING, RESTRUCTURED ELECTRICITY MARKETS, EXPANSION, Power system management, operation and economics, Optimisation techniques
Electric energy storage systems in a market-based economy: Comparison of emerging and traditional technologies
Unlike markets for storable commodities, electricity markets depend on the real-time balance of supply and demand. Although much of the present-day grid operate effectively without storage technologies, cost-effective ways of storing electrical energy can make the grid more efficient and reliable. This work addresses an economic comparison between emerging and traditional Electric Energy Storage (EES) technologies in a competitive electricity market. In order to achieve this goal, an appropriate Self-Scheduling (SS) approach must first be developed for each of them to determine their maximum potential of expected profit among multi-markets such as energy and ancillary service markets. Then, these technologies are economically analyzed using Internal Rate of Return (IRR) index. Finally, the amounts of needed financial supports are determined for choosing the emerging technologies when an investor would like to invest on EES technologies. Among available EES technologies, we consider NaS battery (Natrium Sulfur battery) and pumped-storage plants as emerging and traditional technologies, respectively. (C) 2009 Elsevier Ltd. All rights reserved.
Risk-constrained dynamic self-scheduling of a pumped-storage plant in the energy and ancillary service markets

This work addresses a new framework for self-scheduling of an individual price-taker pumped-storage plant in a day-ahead (DA) market. The goal is achieving the best trade-off between the expected profit and the risks when the plant participates in DA energy, spinning reserve and regulation markets. In this paper, a set of uncertainties including price forecasting errors and also the uncertainty of power delivery requests in the ancillary service markets are contemplated. Considering these uncertainties, a new approach is proposed which is called dynamic self-scheduling (DSS). This risk-constrained dynamic self-scheduling problem is therefore formulated and solved as a mixed integer programming (MIP) problem. Numerical results for a case study are discussed. (c) 2009 Elsevier Ltd. All rights reserved.
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 6.04 SJR 2.287 SNIP 2.065
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 2.09 SNIP 2.092 CiteScore 5.24
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.854 SNIP 2.835 CiteScore 5.35
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.669 SNIP 2.558 CiteScore 4.49
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.732 SNIP 2.277 CiteScore 3.72
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.292 SNIP 1.846 CiteScore 3.03
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.372 SNIP 1.75
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.339 SNIP 1.797
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 1.508 SNIP 1.905
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 1.196 SNIP 1.811
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 1.327 SNIP 1.816
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 1.577 SNIP 1.799
Scopus rating (2004): SJR 1.049 SNIP 1.466
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 0.903 SNIP 1.321
Scopus rating (2002): SJR 1.089 SNIP 1.463
Web of Science (2002): Indexed yes
Scopus rating (2001): SJR 0.81 SNIP 0.855
Scopus rating (2000): SJR 0.576 SNIP 0.688
Scopus rating (1999): SJR 0.515 SNIP 0.724
Original language: English
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Projects:

**Advanced Game-Theoretical Aspects in Electricity Markets**
Department of Electrical Engineering  
Period: 01/09/2017 → 31/08/2020  
Number of participants: 3  
PhD Student:  
Dvorkin, Vladimir (Intern)  
Supervisor:  
Kazempour, Jalal (Intern)  
Main Supervisor:  
Pinson, Pierre (Intern)

**Financing sources**  
Source: Internal funding (public)  
Name of research programme: Institut stipendie (DTU)  
Project: PhD

**Efficient and Scalable Market Design for Renewable-based Integrated Energy Systems**
Department of Electrical Engineering  
Period: 01/09/2017 → 31/08/2020  
Number of participants: 3  
PhD Student:  
Schwele, Anna (Intern)  
Supervisor:  
Kazempour, Jalal (Intern)  
Main Supervisor:  
Pinson, Pierre (Intern)

**Financing sources**  
Source: Internal funding (public)  
Name of research programme: Forskningsrådsfinansiering  
Project: PhD

**Market Mechanisms for Integrated Energy Systems**
Department of Electrical Engineering  
Period: 01/11/2015 → 31/10/2018  
Number of participants: 3  
PhD Student:  
Mitridati, Lesia Marie-Jeanne Mariane (Intern)  
Supervisor:  
Kazempour, Jalal (Intern)  
Main Supervisor:  
Pinson, Pierre (Intern)

**Financing sources**  
Source: Internal funding (public)  
Name of research programme: Samfinansieret - Andet  
Project: PhD

**Market Mechanisms for Integrated Energy Systems**
Department of Electrical Engineering
Period: 01/07/2015 → 30/06/2018
Number of participants: 4
Phd Student:
Ordoudis, Christos (Intern)
Supervisor:
Morales González, Juan Miguel (Intern)
Kazempour, Jalal (Intern)
Main Supervisor:
Pinson, Pierre (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Eksternt finansieret virksomhed
Project: PhD

5s - Future Electricity Markets

Department of Electrical Engineering
Center for Electric Power and Energy
Electricity markets and energy analytics
Period: 01/04/2013 → 31/10/2017
Number of participants: 5
Project participant:
Pinson, Pierre (Intern)
Jensen, Tue Vissing (Intern)
Soares, Tiago (Intern)
Papakonstantinou, Athanasios (Intern)
Kazempour, Jalal (Intern)

Relations
Activities:
European conference for Operational Research 2015
Project

Activities:

DTU Summer School 2017: Modern Challenges in Power System Operation and Electricity Markets: An Optimization Perspective
Period: 12 Jun 2017 → 16 Jun 2017
Jalal Kazempour (Organizer)
Department of Electrical Engineering
Center for Electric Power and Energy
Electricity markets and energy analytics
Degree of recognition: International

Related event
DTU Summer School 2017: Modern Challenges in Power System Operation and Electricity Markets: An Optimization Perspective
12/06/2017 → 16/06/2017
Kgs. Lyngby, Denmark
Activity: Attending an event › Participating in or organising workshops, courses, seminars etc.

International Transactions on Electrical Energy System (Journal)
Period: 1 Jan 2017 → …
Jalal Kazempour (Editor)
On the list of the 47 outstanding reviewers of IEEE Transactions on Smart Grid for 2016

Period: 2016 → 2017

Jalal Kazempour (Awardee)

Department of Electrical Engineering
Center for Electric Power and Energy
Electricity markets and energy analytics

Description
On the list of outstanding reviewers of IEEE Transactions on Smart Grid for 2016

Activity: Other › Other (prizes, external teaching and other activities) - Prizes, scholarships, distinctions

DTU Summer School 2016: Uncertainty in Electricity Markets and System Operation

Period: 4 Jul 2016 → 8 Jul 2016

Jalal Kazempour (Organizer)

Department of Electrical Engineering
Center for Electric Power and Energy
Electricity markets and energy analytics

Description
DTU Summer School 2016 (EES-UETP verified), Technical University of Denmark, “Uncertainty in Electricity Markets and System Operation,” 4-8 July 2016.

Related event

DTU Summer School 2016: Uncertainty in Electricity Markets and System Operation
04/07/2016 → 08/07/2016

Activity: Attending an event › Participating in or organising a conference

Special PhD-level course on "Large-scale optimization problems in energy systems: Applications of decomposition techniques", Spring 2016.


Jalal Kazempour (Course lecturer)

Department of Electrical Engineering
Center for Electric Power and Energy
Electricity markets and energy analytics

Related event

Special PhD-level course on "Large-scale optimization problems in energy systems: Applications of decomposition techniques".
15/02/2016 → 15/07/2016
On the list of the 40 outstanding reviewers of IEEE Transactions on Power Systems for 2015
Period: 2015 → 2016
Jalal Kazempour (Awardee)
Department of Electrical Engineering
Center for Electric Power and Energy
Electricity markets and energy analytics
Activity: Other › Other (prizes, external teaching and other activities) - Prizes, scholarships, distinctions