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Research article

Stochastic optimal generation bid to electricity markets with emissions risk constraints☆

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ABSTRACT

There are many factors that influence the day-ahead market bidding strategies of a generation company (GenCo) within the framework of the current energy market. Environmental policy issues are giving rise to emission limitation that are becoming more and more important for fossil-fueled power plants, and these must be considered in their management. This work investigates the influence of the emissions reduction plan and the incorporation of the medium-term derivative commitments in the optimal generation bidding strategy for the day-ahead electricity market. Two different technologies have been considered: the high-emission technology of thermal coal units and the low-emission technology of combined cycle gas turbine units. The Iberian Electricity Market (MIBEL) and the Spanish National Emissions Reduction Plan (NERP) defines the environmental framework for dealing with the day-ahead market bidding strategies. To address emission limitations, we have extended some of the standard risk management methodologies developed for financial markets, such as Value-at-Risk (VaR) and Conditional Value-at-Risk (CVaR), thus leading to the new concept of Conditional Emission at Risk (CEaR). This study offers electricity generation utilities a mathematical model for determining the unit's optimal generation bid to the wholesale electricity market such that it maximizes the long-term profits of the utility while allowing it to abide by the Iberian Electricity Market rules as well as the environmental restrictions set by the Spanish National Emissions Reduction Plan. We analyze the economic implications for a GenCo that includes the environmental restrictions of this National Plan as well as the NERP's effects on the expected profits and the optimal generation bid.

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1. Introduction

1.1. EU National Emissions Reduction Plan (NERP)

The share of fossil fuels in the world's energy production is more than 85% and in electricity generation more than 60% (Bogdan et al., 2007). Although they provide a reliable and affordable source of energy, the use of fossil-fuelled power plants harm the global ecosystem by emitting noxious gases and toxic substances into the atmosphere, thus causing the greenhouse effect, that is thought to be responsible for climate change. The EU sets limits for emissions of pollutants from large combustion plants through the so-called National Emissions Reduction Plan (NERP) Directive 2001/80/EC (2003). This directive applies to combustion plants (technical equipment in which fuels are oxidized in order to use the heat generated) with a rated thermal input equal to or greater than 50 MW, irrespective of the type of fuel used (solid, liquid or gaseous). This directive limits the amount of sulphur dioxide (SO_2) and nitrogen oxides (NO_x) emitted from large combustion plants each year. Following these commitments, the Spanish public administration launched the Spanish National Emissions Reduction Plan in 2004 (NERP, Real Decreto 430/2004 National emission reduction plan (2007)). The Spanish NERP imposes, for the period 2008-15, a global reduction of 81% of SO_2 and 15% of NO_x emissions

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as compared to 2001 emissions. NERP directive must be inevitably and explicitly considered when elaborating the generation units' optimal sale bid to the wholesale electricity market, and we will see in this study how strongly this directive reshapes the optimal bid, changing the balance between the production of the different generation technologies and the commitment of the medium-term derivatives. The commitment of this work is to propose a new mathematical formulation that extends the current NERP-violation risk-averse models with a more flexible risk-accepting formulation.

1.2. The Iberian Electricity Market (MIBEL)

The Iberian Electricity Market (MIBEL) is the result of a joint initiative by the Governments of Portugal and Spain to integrate their markets. This market is organized by the Iberian Market Operator of Energy (OMIE, according to its Spanish initials), which has to match supply with demand in real time. The day-ahead market (DAM) of day D consists of a series of twenty-four hourly auctions which are cleared simultaneously between 10:00 h and 10:30 h of the previous day (D-1). The clearing price λ_t^D of each hourly auction for time t is determined by the intersection of the aggregated offer and demand curves: Fig. 1. All the sale/purchase bids with a lower/greater bid price are matched and will be remunerated at the same clearing price λ_t^D, whichever the original bid price.

Bilateral contracts (BC) are agreements between a GenCo and a qualified consumer to provide a given amount of electrical energy at a stipulated price along with a delivery period. The agreement terms are, namely, the energy, the price and the delivery period, all of which are negotiated several days before the DAM with the restriction that the energy destined to the BC cannot be included in the DAM. A futures contract (FC) is an exchange-traded derivative that represents agreements to buy/sell some underlying asset in the future at a specified price (Hull, 2008). The DAM's operator demands that every GenCo commit to the quantity designated to each FC through the DAM bidding of a given set of generation units. This commitment is made through a sale offer with a bid price of 0€/MWh, the so-called *price accepting bid*. All price accepting bids will be matched (i.e., accepted) in the clearing process meaning that the energy shall be produced and will be remunerated at the DAM spot price.

1.3. Generation units

This work considers a GenCo with a set of coal thermal units (high emission technology) and combined cycle gas turbine (CCGT) generation units (low emission technology). The combined cycle gas turbine units represent a combination of combustion and steam turbines in a power plant (Heredia et al., 2012). The CCGT plants employ more than one thermodynamic cycle thus improving the efficiency of electricity generation (Bachmann et al., 1999). Currently, most of the new generating unit installations in Europe are CCGT units. They are between 20 and 30% more efficient than thermal power plants, and can reach up to 60% efficiency. According to Bachmann et al. (1999), gas turbines in combined-cycle plants produce a practically complete combustion with very low concentrations of unburned elements such as CO or hydrocarbons. Consequently, they cause less climate-damage because they do not produce SO_2 emissions at all, and the NO_x emissions are negligible in comparison with those of thermal units.

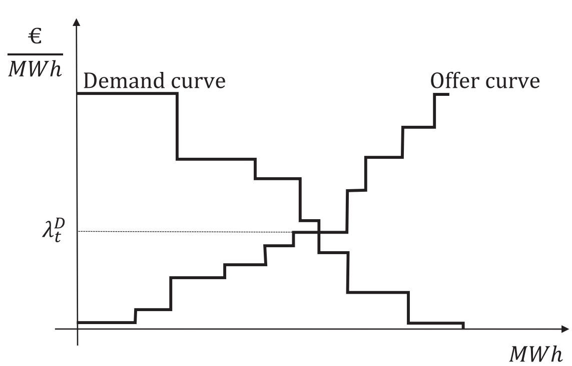

Fig. 1. Market clearing for a certain hour: intersection of the aggregated offer and demand curves.

2. Literature review and contributions

2.1. Literature review

The greater part of the published works concerning the relationship between energy production and pollutant emissions are devoted to studying the impact of CO_2 emissions being traded in the power industry, especially through medium-term models (Gnansounou et al., 2004; Reneses and Centeno, 2008; Sousa et al., 2005) but also some that are short-term (Kockar et al., 2009). None of this papers consider the SO_2 and NO_x emissions, which is the goal of the NERP, although these rules substantially modifies the shape of the optimal bid strategy of an electricity producer. Actually, quite a bit of attention has been paid in the bibliography to the optimal generation bid strategies under SO_2 and NO_x emission limits. Most of the research production related to SO_2 and NO_x emissions has been dedicated to general long-term studies of different aspects of the impact of reducing the SO_2 and NO_x emissions in the wholesale electricity production system but without any explicit mention to the NERP (Funakin et al., 2011; Tang and Zhou, 2012). Among the few papers that study optimal generation under emission limits, (Liu, 2011) develops a load dispatch model to minimize NO_x emissions only by taking fuel cost and stochastic wind power availability as constraints, thus disregarding the electricity market entirely. The model in Lu and Shahidehpour (2005) considers a classical deterministic unit commitment of both thermal and combined cycle units; this minimizes the generation (fuel) costs (no electricity market) by satisfying simple bounds on SO_2 and NO_x emissions. A quite common approach by several recent papers to the handling of emission limits involves using multiobjective optimization techniques in which both profits and emissions are minimized (Shayanfar et al., 2012; Peng et al., 2012; Jadid and Vahidinasab, 2011), sometimes with additional emissions limit constraints (Catalao and Mendes, 2011). Despite the interest of all these studies, it is worth mentioning that none of them are optimal-bid models, as their formulations do not incorporate the bid rules of the electricity market, and the influence of the electricity market is reduced either to a deterministic forecasting of the electricity prices (Shayanfar et al., 2012; Catalao and Mendes, 2011; Peng et al., 2012) or to the use of spot price scenarios (Jadid and Vahidinasab, 2011). Some recent works have taken into account CO_2 emission constraints in the self-scheduling of thermal units (not CCGT units) that operate in electricity markets through two-stage stochastic programming (Geng et al., 2017; Laia et al., 2015; Rebennack et al., 2012). A flaw of these studies is that the emission limits are imposed as hard constraints that avoids the violation of emission limits for every scenario, even for the most unlikely scenarios, which, as we will show in this paper, is quite a restrictive modelization. A general flaw of the revised works is that they neglect both the specific rules of the day-ahead markets, including the handling of futures and bilateral contracts, and the NERP rules.

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